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DEVELOPMENT OF A STANDARD DEXTERITY TEST BATTERY (U)

KATHLEEN M. ROBINETTE

ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY

CAY ERVIN
GREGORY ZEHNER

ANTHROPOLOGY RESEARCH PROJECT, INC.

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HUMAN SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Director, Human Engineering Division
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Numerous commercially available dexterity tests were evaluated for use in a standardized dexterity test battery to be used to assess the effects of chemical defense treatment drugs on manual performance. Twenty-six of these tests were administered to 118 subjects (60 females and 58 males). Factor analysis was used to identify tests which appeared to measure similar skills. The number of tests in the battery was reduced from 26 to seven by selecting one test from each identified skill group on the basis of factor loading, ease of administration, and equipment durability.

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SUMMARY

The purpose of this study was to develop a standardized battery of dexterity tests to be used in assessing the effects of chemical defense treatment drugs on manual performance. The study included a review of readily available test devices, classification of tests by skills measured, modification of test procedures and instructions for standardization purposes, administration of 26 tests to a group of subjects, factor analysis of relationships, and selection of a set of seven tests for the final test battery. Each of these aspects is discussed in detail in this report.

Two companion reports are also being prepared. One is an annotated bibliography of related research (Ervin, in press), and the other is an instruction manual for administration of the selected tests (Ervin and Robinette, in press).

The seven tests selected for the battery are: Purdue Pegboard-Assembly, Aiming, Photoelectric Rotary Pursuit-Circle, Reaction Time, Nine-Hole Steadiness Test (two tests), and Tapping. Selection of the tests was based on the factor analysis results as well as on other considerations such as the ease with which a test can be administered or standardized. Each test should effectively represent a different component of dexterity skill. These skills are also discussed.

PREFACE

This study was conducted by the Anthropology Research Project, Inc. under Air Force Contract F33615-85-C-0531 (Task 718408) with the U.S. Air Force Harry G. Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio.

The authors would like to thank Dr. M. V. Ratnaparkhi of Wright State University for his statistical advice, and Mr. Edwin A. Fleishman for providing the paper and pencil tests. They also wish to acknowledge Ms. Mary Gross and Ms. Jo Lynn Ross for their assistance with data collection, and Mr. Thomas Churchill for the preparation of the tables.

Ms. Ilse Tebbetts and Ms. Belva Hardin, Anthropology Research Project, edited and prepared the manuscript for publication.

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DEVELOPMENT OF A STANDARD DEXTERITY TEST BATTERY

INTRODUCTION

The purpose of this study was to develop a standardized battery of dexterity tests to be used in assessing the effects of chemical defense treatment drugs on manual dexterity. The object was to derive a compact group of tests to measure a wide variety of dexterity (or psychomotor) skills. Information obtained from this test battery will aid in the selection of a chemical defense treatment drug which produces maximum protection for military personnel with minimum loss of performance. This report describes the procedures used to develop the battery. It serves as a companion to an instruction manual for conducting the tests (Ervin and Robinette, in press).

Following a recent literature review of dexterity tests (Ervin, in press), as many commercially available tests as were obtainable were acquired. Each one was reviewed for reliability (standardization), accuracy, validity, maintainability, administration and scoring procedures, and the number of practice trials needed to control for learning effects. Of the tests which did not "pass" this evaluation (see Appendix A), some were discarded while others were modified.

The tests were also classified according to the skills they measured. Where tests of specific skills were lacking they were created. Twenty-six tests were then administered to 118 subjects. The tests, test procedures, and measured skills are described in Chapter 1.

Through results of factor analysis and considerations of the cost and durability of the equipment, and ease of test administration, the number of tests was reduced from 26 to seven. This set of seven manual dexterity tests is believed to quantify a variety of different functions of human manipulative skill with minimum redundancy. The analysis and rationale for final test selection are described in Chapter 2.

CHAPTER 1

METHODS AND EQUIPMENT

SUBJECTS

Sixty males and sixty females from a subject pool maintained by Systems Research Laboratories, Inc. (Beavercreek, Ohio) participated in the study. Subjects were selected without regard to age (Jebsen et al., 1969, showed that only extreme ages affect scores) or handedness. While the majority of these subjects were college students whose ages ranged from 18 to 67 for males, and from 18 to 58 for females, the average age of both groups was 24. All subjects had the full use of hands and arms.

Equipment failure and an error in the administration of one test resulted in the elimination of data for two male subjects. The final sample size was 118.

EXPERIMENTAL DESIGN

Twenty-six dexterity tests, ranging from paper and pencil tests through hands-on apparatuses to computer-administered and scored tests, were selected for pilot testing. As a group, they were designed to test a variety of skills such as speed, two-handed coordination, aiming, and steadiness. Judgments about which test instruments were likely to test which skills were made on the basis of information gleaned from the literature review, from descriptive materials accompanying the tests, and from examining the devices themselves. Factor analysis later provided support for these intitial estimates.

Table 1 is a list of the tests categorized according to the skills they were thought to measure. (It should be noted that very few dexterity tests appear to measure a single/specific skill. More often they measure the interaction of several skills, and therefore some tests appear in Table 1 under more than one skill category.)

Each test instrument was pilot-tested on groups of subjects to determine the possible need for modifications in administration and/or scoring. Many, for example, were originally scored by the amount of time it took a subject to complete a given number of repeated tasks. These were modified so that a set time was given, and scores were based on the number of times a given task was completed in that time period. This modification served to shorten the tests and facilitated planning the amount of time required for each testing session.

The tests were administered to each subject in two sessions of approximately three-and-a-half hours each, on two separate days. Thirteen tests were completed in each time block. Since some tests, particularly the electronically scored tests, are scored by two variables, error time (or number of errors) and completion time, a total of 35 actual measurements were taken on the 26 tests.

Subjects presented themselves in pairs but were tested separately by different administrators. A computer-generated randomization procedure (see Appendix B, Figure B-1) was used to eliminate the effect of test order on the results.

TABLE 1

SKILL CATEGORIES OF TESTS

Skill	Test
Control precision: the ability to move controls to exact positions, repeatedly and accurately.	Photoelectric Rotary Pursuit Grooved Pegboard Numeric Keypad
Multilimb coordination: the ability to coordinate the movements of two hands and arms.	Two Arm Coordination
Steadiness: the ability to keep the arm and hand steady.	Groove Steadiness Test Nine-Hole Steadiness Test
Manual dexterity: the ability to make skillful coordinated movements to grasp, move, or assemble objects both with and without tools.	Pennsylvania Bi-Manual Worksample Minnesota Rate of Manipulation-Turning Purdue Pegboard Crawford Small Parts Dexterity Test Roeder Manipulative Aptitude Test
Finger tactility: the ability to repeatedly identify and manipulate small objects using tactile sense.	Roeder Manipulative Aptitude Test O'Connor Finger Dexterity Test
Aiming: the ability to visually locate and accurately place or follow objects.	Pursuit Aiming II Medium Tapping Test Aiming Test Tracing Test Photoelectric Rotary Pursuit Mirror Tracer
Speed: the ability to make repeated movements quickly.	Tapping Test
Reaction Time: the speed of response to a stimulus.	Reaction Time Test

To ensure that a true measure of ability to perform (rather than the ability to learn) was obtained, the number of practice trials required to control for learning effects was established in pilot testing. During pilot testing ten to twelve subjects completed a series of trials for each test. The average scores for each trial were then plotted and the point at which scores plateaued was identified. Figures 1 through 5 illustrate these plots. This information was then used to determine the number of practice trials required to control for learning effects on each test. For example, Two Arm Coordination (Figure 1) and Mirror Tracer (Figure 2) show that twelve trials are needed while the Pennsylvania Bi-Manual Worksample (Figure 3) required six and the Purdue Pins-Both Hands (Figure 4) and the Grooved Pegboard (Figure 5) each required five practice trials.

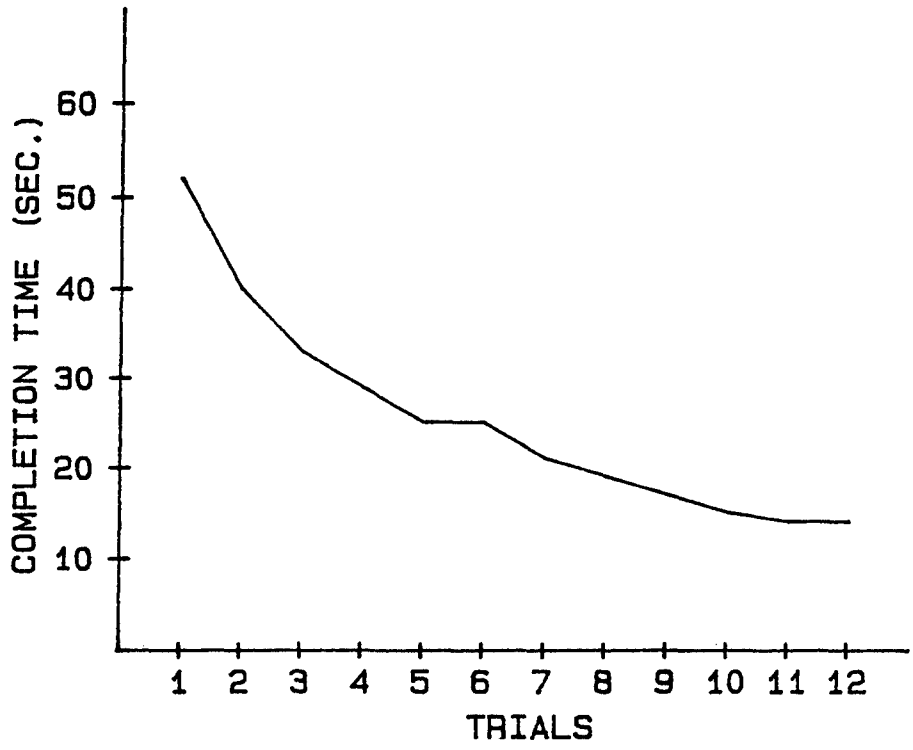

Figure 1. Two Arm Coordination Test learning curve.

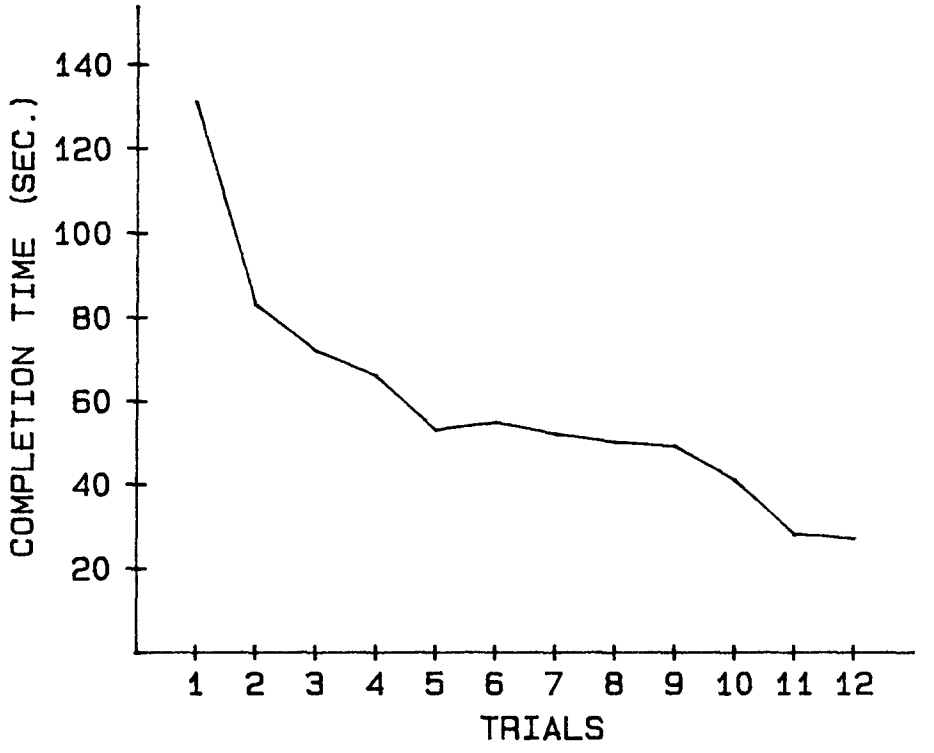

Figure 2. Mirror Tracer Test learning curve.

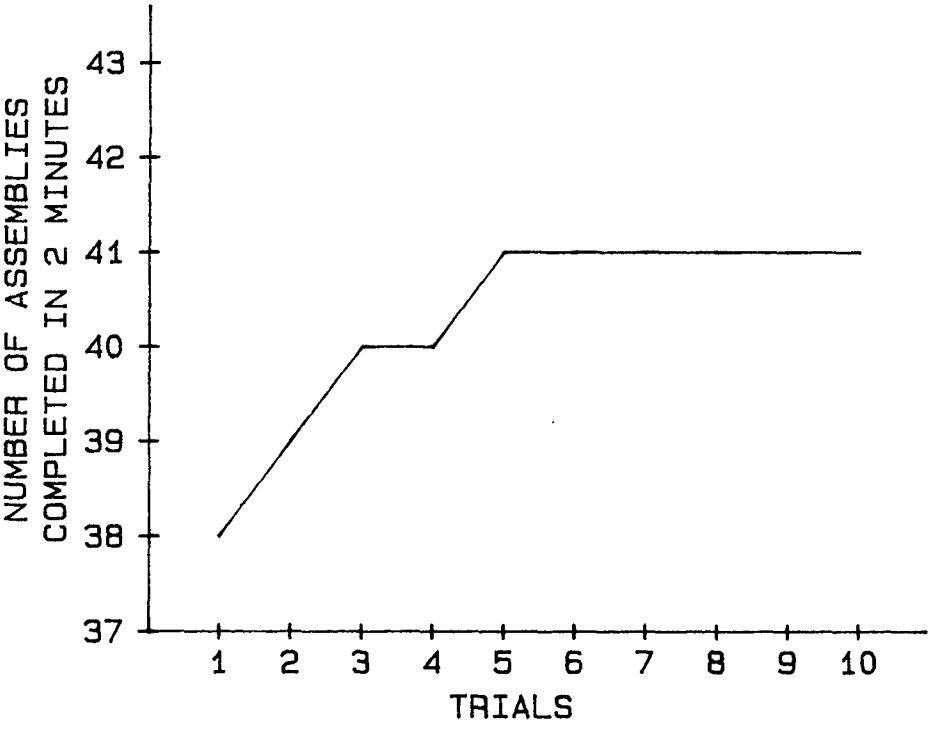

Figure 3. Pennsylvania Bi-Manual Worksample--
Assembly learning curve.

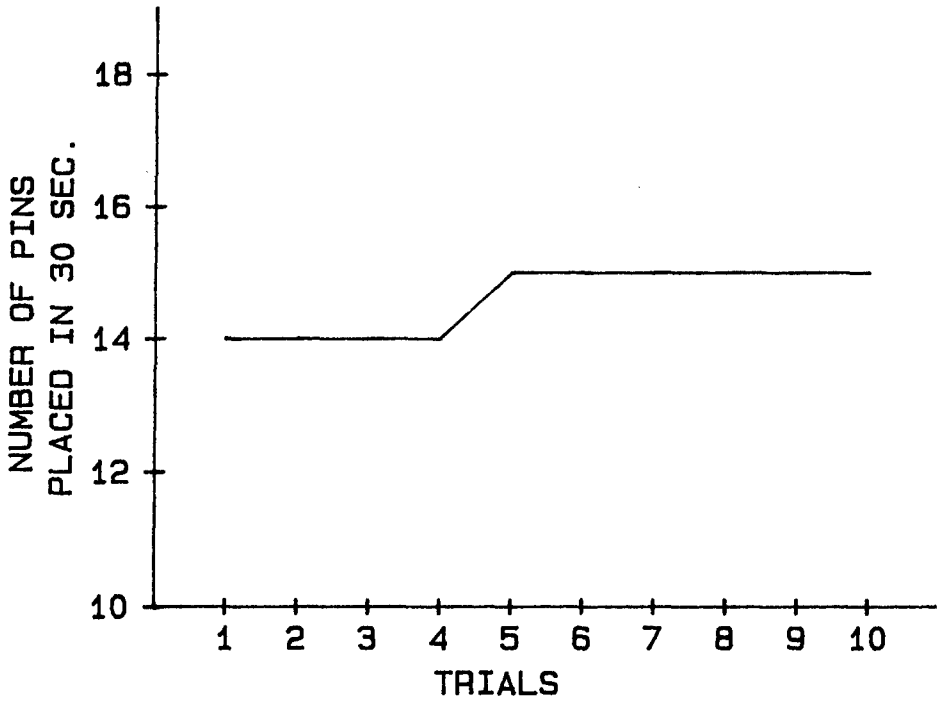

Figure 4. Purdue Pegboard--Pins (Both Hands) learning curve.

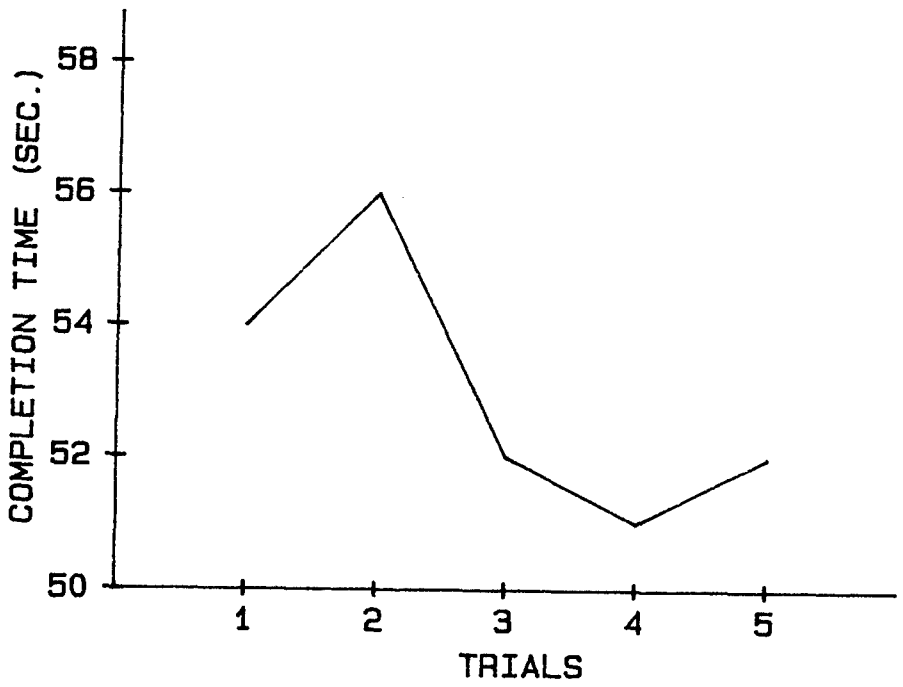

Figure 5. Grooved Pegboard learning curve.

Following are brief descriptions of the equipment, and, where applicable, of modifications made to the scoring and/or administration procedures. Instructions used for administering the tests and directions given to the subjects taking the test appear in Appendix B.

AIMING TEST

The object of this paper and pencil test is to place dots inside a series of small circles, 1/8 inch in diameter, as quickly as possible (Figure 6). Instructions call for scoring to be recorded by the number of dots successfully placed in 60 seconds.

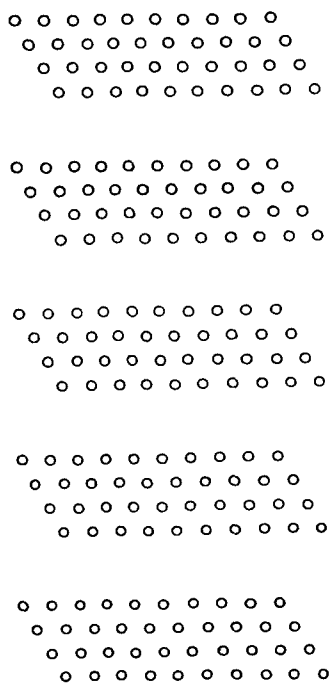

Figure 6. Aiming pencil and paper test.
(Actual size of the test sheet is 8 1/2" x 11".)

Revisions

During pilot testing many subjects complained of monotony and quickly became bored. As a result the allotted time was decreased from 60 to 30 seconds. Procedures were standardized by providing soft-pointed felt-tip pens and instructing subjects to begin with pen in hand and hand resting on the table beside the paper. Practice trials were not mentioned in the original instructions; four trials were administered for this study.

CRAWFORD SMALL PARTS DEXTERITY TEST

The Crawford Small Parts Dexterity Test (Figure 7) is a wooden board containing both threaded and smooth holes. Three wells hold pins, collars and screws. The board is arranged with the wells farthest from the subject and the bottom edge parallel to the table edge. The distance from the edge of the table may be adjusted for arm length. This equipment is used for two tests: Crawford Screws and Crawford Pins and Collars.

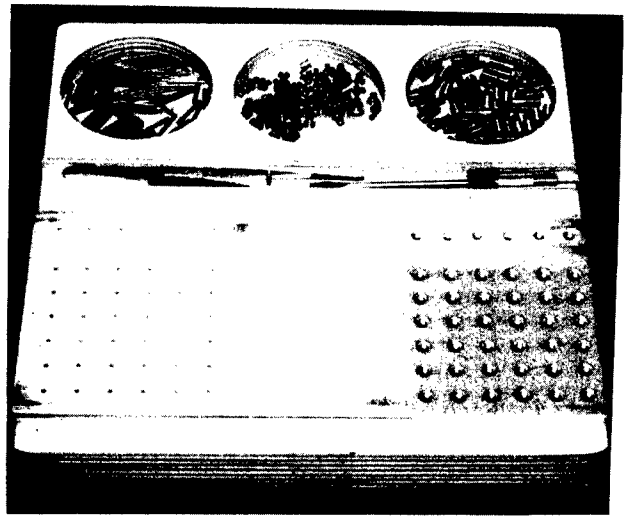

Figure 7. Crawford Small Parts Dexterity Test.

Crawford Screws

The Crawford Screws test is a two-handed test which measures the ability to use a small screwdriver to turn screws into threaded holes. Test instructions call for scoring by the length of time it takes to fill 36 holes. One row of six holes is designed to be used for practice.

Revisions

To streamline administration, and to shorten the test, the scoring procedure was changed to record the number of screws successfully placed in two minutes and 30 seconds. The starting position, not specified in the manual, was standardized so subjects began with a screw in the dominant hand, the screwdriver in the other hand, and both hands resting on the table (one on each side of the board). One row of practice holes was found to be insufficient to completely learn the test; this was changed to five complete trials.

Crawford Pins and Collars

The Crawford Pins and Collars test is a dominant-hand test which measures the ability to use tweezers to place small pins in close-fitting holes and to place collars on top. According to the test manual, subjects use one row of six holes for practice, and are scored by the length of time required to fill the remaining 36 holes.

Revisions

As with the Crawford Screws test the scoring procedure was changed to facilitate administration and to shorten the test; subjects were scored by the number of pieces placed in two minutes and 30 seconds. Practice was increased

from one row to five practice trials. The starting position was standardized by having subjects begin with the tweezers in the dominant hand which rests on the table beside the board.

GROOVE STEADINESS TEST

The Groove Steadiness Test (Figure 8) consists of two adjustable metal plates indexed in centimeters and mounted in a V-shaped configuration on a wooden frame. Beneath the plates is a mirror. The object is to move a stylus the length of a gradually narrowing groove without touching the sides of the plates. When the latter occurs, an error is electronically recorded. The instructions which came with the test are incomplete but it appeared that performance was somehow measured by recording the exact point at which the stylus touched the plate.

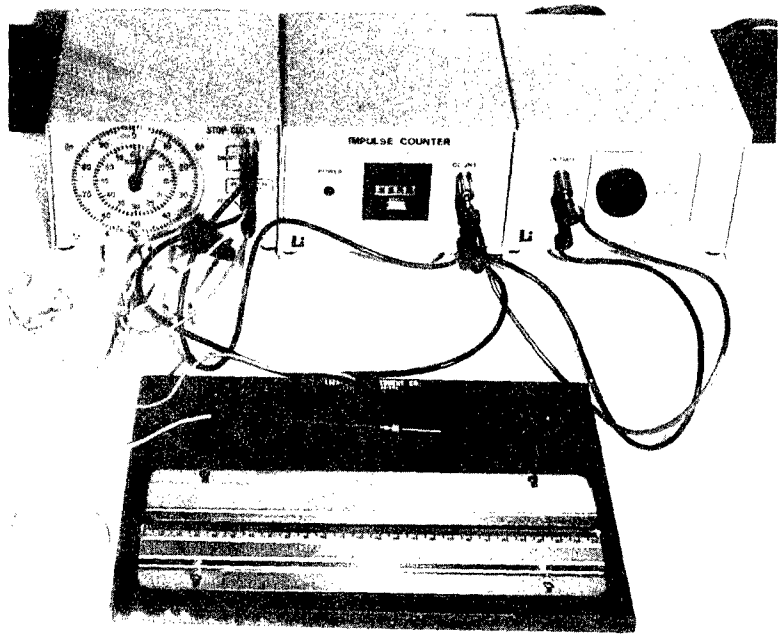

Figure 8. Groove Steadiness Test.

Revisions

It was discovered during pilot testing that it was extremely difficult to discern the point at which subjects touched the sides of the groove with the stylus. As a result the scoring procedure was changed to record error time and completion time, and the plates were set parallel to one another 1/8 inch apart. Error time was found to be a more accurate measure than the number of errors because a subject could hold the stylus next to the plate for the length of the groove and only one error would be recorded. Electrical tape was placed over the mirror to reduce the glare. Administration of this test was standardized by stipulating that the long edge of the board be placed parallel to the edge of the table, that the hand and arm could not be rested

on the table, and that subjects begin with the tip of the stylus in contact with the beginning of the groove. Three practice trials were found to be sufficient to familiarize subjects with the test.

GROOVED PEGBOARD TEST

The Grooved Pegboard Test (Figure 9) has two hinged four-inch square wooden blocks. One block contains the well for the pegs and the other has a metal plate containing 25 irregularly-shaped holes. Each peg has a key on one side and must be rotated to match the hole before it can be inserted. The object is to use the dominant hand to place one peg in each hole, as quickly as possible. The test is scored by the length of time needed to place pegs in all the holes.

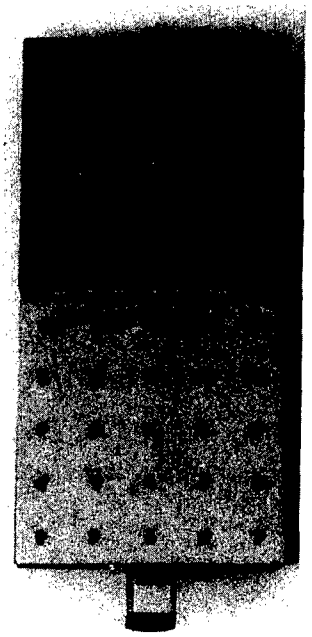

Figure 9. Grooved Pegboard Test.

Revisions

The only modification made on this test was to change the scoring procedure to record the number of pegs placed in 30 seconds. The amount of practice was not specified, but five complete trials seemed sufficient to control for learning effects. The test was further standardized by specifying that subjects begin with a peg in the dominant hand, and with that hand resting on the table beside the board.

MEDIUM TAPPING

In this test subjects are asked to place three dots in a series of circles 3/8 inch in diameter (Figure 10). It is scored by the number of

circles in which three dots are successfully placed in a 30-second period. A smaller pattern of four rows of circles is given for practice.

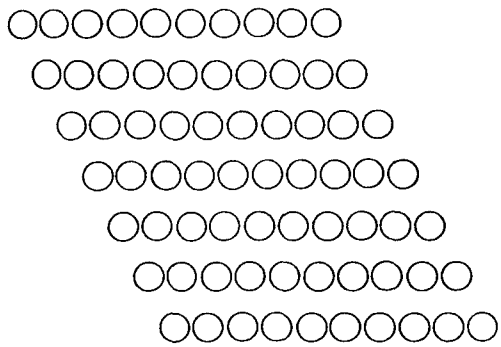

Figure 10. Medium Tapping pencil and paper test.
(Actual size of test sheet is 10" x 8".)

Revisions

The original directions were not changed but were standardized by having all subjects use a fine point pen, and begin with their hands on the table. Practice trials were increased to four complete trials of the actual test sheet.

MINNESOTA RATE OF MANIPULATION-TURNING TEST

The Minnesota Rate of Manipulation Test (Figure 11) comes with two laminated pressboards containing rows of holes filled with plastic disks. There are five tests--Placing, Turning, Displacing, One-Hand Turning and Placing, and Two-Hand Turning and Placing--which require subjects to move or turn the disks in some specified manner. These tests are taken with the subject standing, and with the board positioned so that the long edge is parallel with the table edge. For this study, only the Turning Test was selected because it appears to require the most coordination of both hands. In this test, subjects pick up a disk with one hand and return it to the same hole with the other hand, bottom side up. The object is to turn all the disks in a specified order as quickly as possible. It is scored by the number of seconds needed to complete the board.

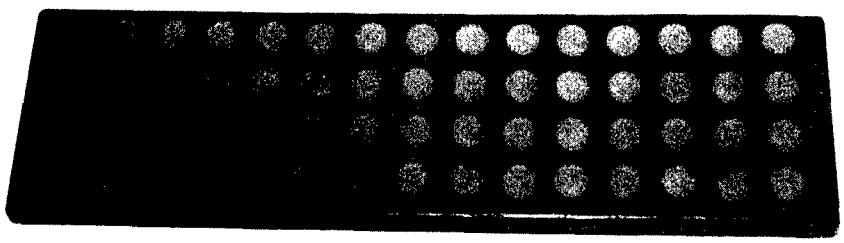

Figure 11. Minnesota Rate of Manipulation.

Revisions

The only change made to this test was to increase the amount of practice allowed from one to five trials.

MIRROR TRACER TEST

The Mirror Tracer Test (Figure 12) is a board on which two six-pointed star patterns are mounted, one inside the other, with a one-quarter inch path between them. On the edge farthest from the subjects is a mirror set perpendicular to the board. A shield is adjusted over the pattern so that subjects do not see their hands or the pattern directly, but only in the mirror. The object is to draw a line between the parallel lines of the pattern from visual cues which are inverted and reversed in the mirror. The test is scored by the number of errors made.

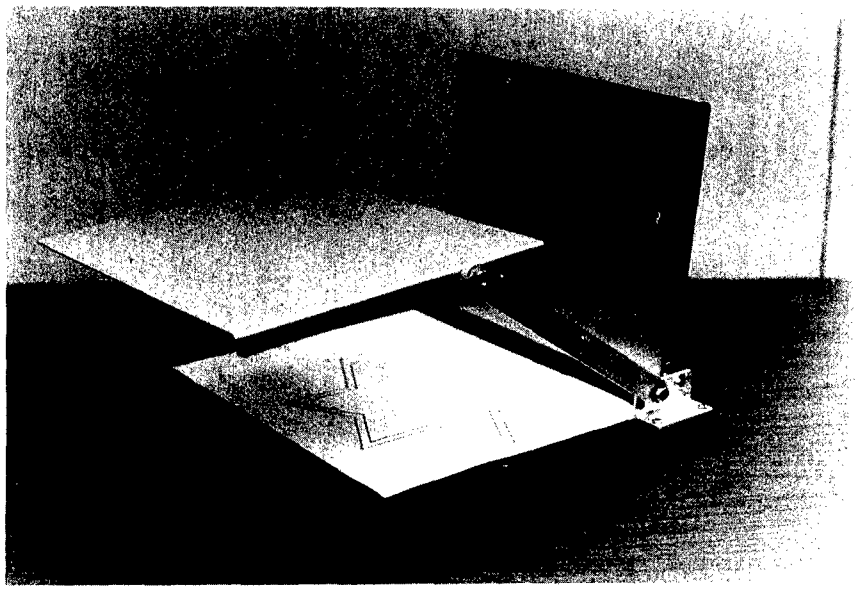

Figure 12. Mirror Tracer Test.

Revisions

In the original version errors were recorded when subjects touched one of the lines on the pattern. For this study errors were recorded when the line was crossed (this was easier for administrators to detect). Total completion time was added to the scoring procedures to further differentiate between levels of skill. The starting position was standardized by having all subjects start with the tip of the pen touching the paper at the bottom center portion of the pattern. All subjects used their dominant hand and moved in a clockwise direction. The amount of practice needed to master the test was not mentioned in the test instructions. For this study subjects were given 12 practice trials.

NINE-HOLE STEADINESS TEST

The Nine-Hole Steadiness Test (Figure 13), is a metal plate with nine holes of gradually smaller sizes; diameters range from 0.5 to 0.078 inches. The subject is asked to hold a stylus 0.06725 inches in diameter in each hole without touching the sides.

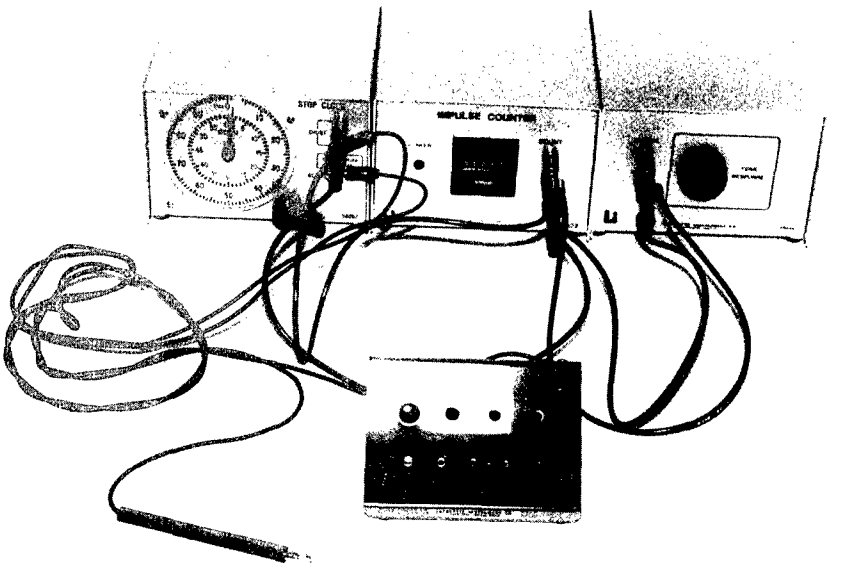

Figure 13. Nine-Hole Steadiness Test.

This test was of particular interest because of references in the literature to the correlation between steadiness tests and rifle marksmanship (Fleishman, 1953). In one such study (Spaeth and Dunham, 1921) investigators reported a correlation of .61 between "a test of precision in thrusting a stylus at a graded series of holes and target rifle shooting".

Revisions

The instructions accompanying this test lacked precision so a considerable amount of work was done to make it suitable for purposes of this study. The instructions called for subjects to hold a stylus in the holes for "10-15 seconds". This range proved to be too wide and was standardized at ten seconds. Because errors were often made entering and/or withdrawing from the holes, the ten-second time period was not begun until the stylus was inserted and subjects indicated that they were ready. They were told not to withdraw the stylus until 10 seconds had passed.

The largest and smallest holes were eliminated because they were too easy or virtually impossible, respectively. Subjects were specifically instructed to hold the stylus by the red plastic handle because one subject was shocked by static electricity when he held the stylus by the metal tip. The test was

largest holes were used (Large-Holes Steadiness Test); the four smallest (Small-Holes Steadiness Test) were used in the second trial. The center hole was used in both. For the larger holes subjects were not permitted to rest their hands. For the smaller holes, they were allowed to rest their hands in any manner they found comfortable. Subjects were given two complete practice trials to become familiar with the test.

NUMERIC KEYPAD TEST

The Numeric Keypad Test, taken on an Apple IIE microcomputer, was designed to simulate hand movements used by pilots or control station operators. (In some cockpits, a small numeric keypad is used to set radio frequency and course.) This test requires subjects to duplicate a series of 15 random numbers ranging in length from three to ten digits, for a total of 88 separate digits in each trial. This is done by using the index finger of the dominant hand to press down numbered keys. The numbers to be duplicated are presented one at a time with a new number appearing after the return key is pressed. Numbers are presented as quickly as subjects can respond, and corrections can be made until the return key is pressed. The test is scored by number of errors and completion time. Subjects are given four complete trials for practice.

Revisions

This test was specifically designed for this study so no revisions were required.

O'CONNOR FINGER DEXTERITY TEST

The O'Connor Test (Figure 14) consists of a hard plastic board containing 10 rows of 10 holes each, and a large well to hold small pins. With the board placed with the well near the dominant hand, the object is to pick up three pins at once, using the dominant hand, and place them in one hole. The test was originally scored as follows: the number of seconds used to complete the first 50 holes, plus the number of seconds (multiplied by 1.1) used to complete the second 50 holes, the sum divided by two. One row of 10 holes was allowed for practice.

Revisions

Several administration changes were made in this test. First, the board was rearranged with the well at the top to prevent the subject from bumping the board and spilling or dislodging the pins. Second, the scoring procedure was simplified to record the number of holes filled in three minutes. Finally the amount of practice allowed was increased from one row to five complete trials. The starting position was standardized by having subjects begin with three pins in the hand and the hand resting on the table beside the board.

Figure 14. O'Connor Finger Dexterity test.

PENNSYLVANIA BI-MANUAL WORKSAMPLE

The Pennsylvania Bi-Manual Worksample (Figure 15) is a large plastic board containing 10 rows of 10 holes each and a large well at both ends for nuts and bolts. Two tests can be conducted with this apparatus: assembly and disassembly.

In the assembly test, subjects thread a nut onto a bolt, just far enough to hold the pieces together, and then place the head of the bolt into a hole. In the disassembly test the nuts and bolts are disassembled and returned to the wells from which they came. Subjects are scored by the length of time taken to fill all the holes with nut and bolt assemblies (assembly test), and by the length of time required to take the pieces apart and replace them in the wells (disassembly test).

Revisions

Because the disassembly task appeared to provide much the same information as provided by the assembly task, it was eliminated. To shorten the assembly task and facilitate its administration, the scoring procedure was changed to record the number of assemblies completed in two minutes. Practices were increased from one trial of two rows, to six trials of two minutes each. The starting position was not stipulated in the manual. For this study it was standardized by having subjects begin with a piece in each hand and with hands resting on the table (one on each side of the board).

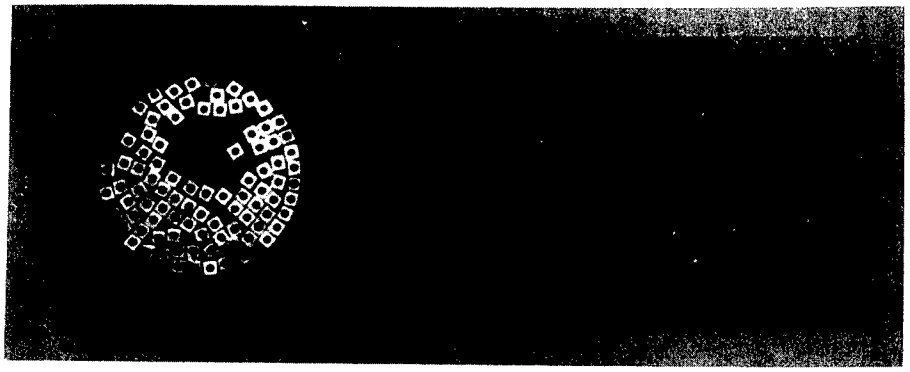

Figure 15. Pennsylvania Bi-Manual Worksample test equipment.

PHOTOELECTRIC ROTARY PURSUIT

The Photoelectric Rotary Pursuit (Figure 16) consists of a rotating opaque black disk, 12 1/2 inches in diameter, mounted over a light in a square box. The light can be seen through a three-quarter-inch-wide translucent strip which extends as a radius from the center of the disk to its perimeter. For the test, one of three opaque black glass plates containing three-quarter-inch translucent templates of various geometric shapes (circle, triangle or square) is fitted on the box over the disk. When the disk revolves under the template, the light coming through the narrow strip on the disk appears to move around the translucent shape outline on the black glass plate. The subject is given a six-inch long wand and is asked to use this to follow the light around the shape. The disk can revolve in a clockwise or counterclockwise direction at speeds which can be adjusted up to 100 rpm. Subjects use their dominant hands and are scored by time on and time off the target pattern.

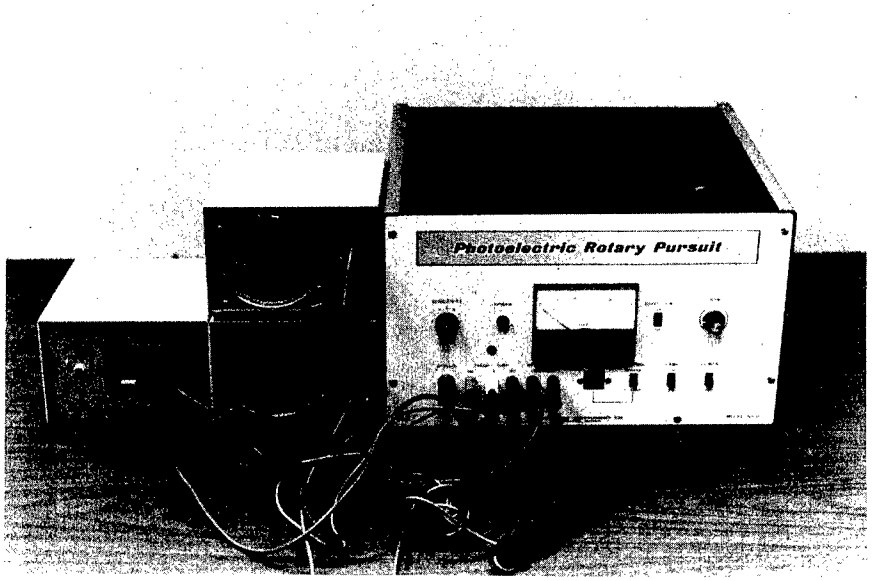

Figure 16. Photoelectric Rotary Pursuit.

Revisions

No revisions were made to the original instructions, but the test required standardization for our purposes since it was designed to be used in several different ways. (Length of time or number of laps, direction and speed could all be set by the experimenter.) For this study the triangle pattern was eliminated because in pilot testing the scores on the triangle and square patterns appeared very similar. The square and circle patterns were retained as two separate tests. The speed was set at 20 rpm, with the pattern moving clockwise. Each trial consisted of ten laps. Subjects started with the tip of the wand in contact with the glass plate over the light and were given five practice trials.

PURDUE PEGBOARD

The Purdue Pegboard (Figure 17) is a formica-covered piece of particle board with two columns of 25 holes each running down the length of the board. Four wells which hold washers, pins and collars are lined up across one short end. When used, the board is positioned so that the wells are farthest from the subject and the other short edge is parallel with the edge of the table. The distance of the board from the edge of the table may be adjusted for arm length. This equipment is used for the following three tests.

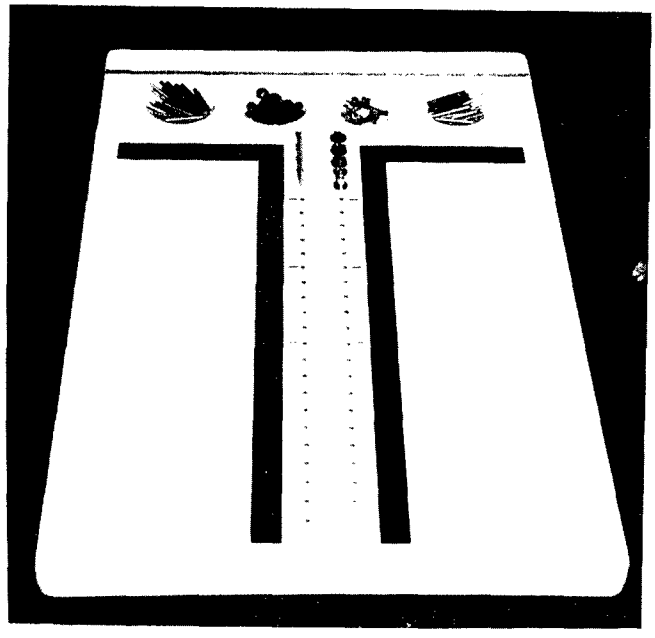

Figure 17. Purdue Pegboard.

Purdue Assembly

The Purdue Assembly test requires subjects to use both hands in an alternating fashion to assemble a pin, a washer, a collar, and another washer,

in a hole on the board. The test is scored by the number of parts placed in one minute. Thus, five completed assemblies and a partial assembly of two parts would yield a score of 22.

Revisions

For the Assembly test the scoring procedure was not changed but the number of recommended practices was increased from three to seven trials. More practice appeared to be required for subjects to learn the rhythmic pattern of movement needed to assemble parts in the right order with alternating hands. The starting position was standardized by having subjects begin with a pin in the right hand, the left hand empty, and both hands resting on the table (one on each side of the board).

Purdue Pins, Dominant Hand

The original version of the Purdue Pins tests called for testing each hand separately. To decrease redundancy it was decided to test the dominant hand only. The object of the test is to place as many pins as possible in the column closest to the dominant hand in 30 seconds.

Revisions

To more adequately control for learning effects the amount of practice given to subjects was increased from "inserting a few" to five complete trials. The starting position was not specified in the manual. To standardize administration procedures, all subjects started with a pin in the dominant hand, and both hands resting on the table (one on each side of the board).

Purdue Pins, Both Hands

In this test subjects use both hands simultaneously to pick up pins from the well closest to each hand and place them in holes in the column closest to that hand. Subjects are given 30 seconds to place as many pairs of pins as possible.

Revisions

As with the dominant hand test the number of practice trials was increased to five 30-second trials. The starting position was standardized so subjects began with a pin in each hand, and both hands resting on the table (one on each side of the board).

PURSUIT AIMING II

The object of this paper and pencil test is to follow a pattern of small circles, 1/8 inch in diameter, placing a dot in each circle (Figure 18). The test is scored by the number of dots successfully placed in 60 seconds. Practice trials were not mentioned in the accompanying literature.

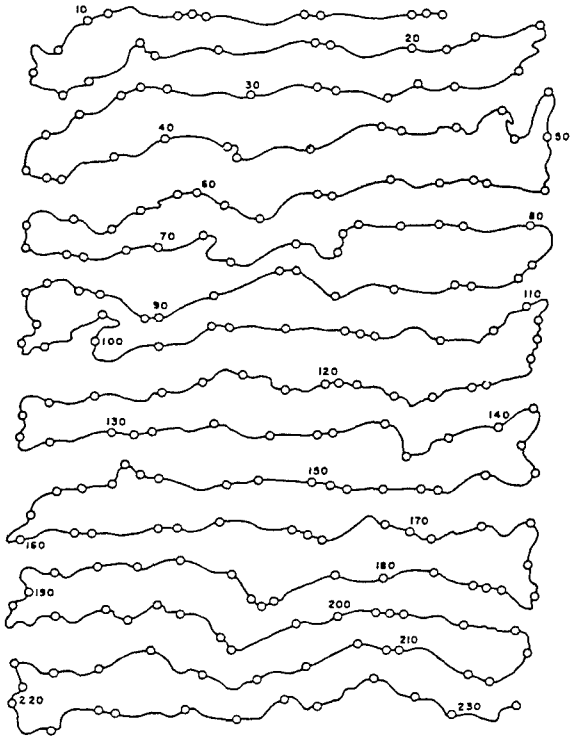

Figure 18. Pursuit Aiming II pencil and paper test.
(Acutal size of the test sheet is 8 1/2" x 11".)

Revisions

Though no changes were made to the original version of the test it was standardized by stipulating the subject's starting position (with pen in hand and hand resting on the table beside the test sheet), the type of pen to use (soft, felt tip), and the number of practice trials (four). The original test pattern covered two pages, but since no subjects finished the first page in the allotted time during the pilot testing, the second page was eliminated.

REACTION TIME TEST

This test was designed to make use of an Apple IIE microcomputer to provide a measure of eye-hand coordination speed. The object of the test is to tap a key as soon as possible after seeing a visual stimulus. The time interval between the presentation of each stimulus ranges from .5 to 5 seconds. There are 10 stimuli in each trial, and three complete trials are given for practice. The test is scored by three variables: the average reaction time, the number of false starts, and the number of errors.

Revisions

The Reaction Time Test was specifically designed for this study so no revisions were made.

ROEDER MANIPULATIVE APTITUDE TEST

The Roeder Manipulative Aptitude Test is a plexiglass board with four receptacles for holding washers, rods, caps and nuts (Figure 19). The board is positioned with the wells nearest to the table edge. The long edge of the board should be parallel to the edge of the table while the subject takes the test. This equipment is used for the following three tests.

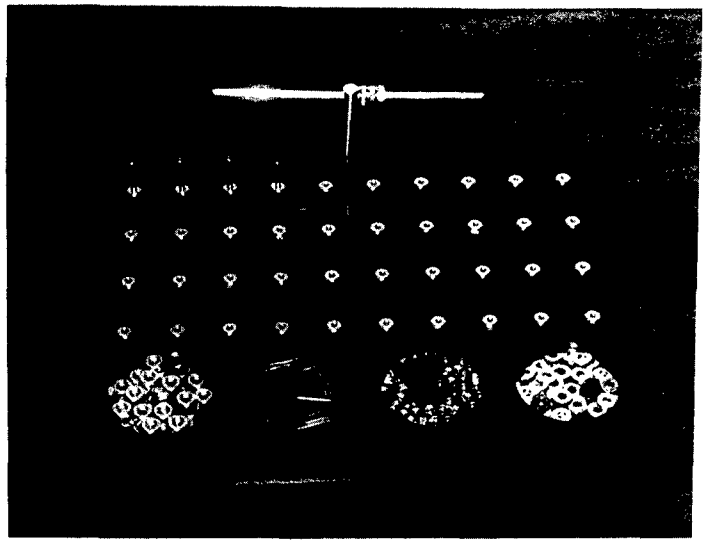

Figure 19. Roeder Manipulative Aptitude Test.

Rods and Caps

In this one-handed test subjects screw rods into threaded holes in the board, and screw caps on top of the rods. Separate scores are kept of the number of rods and the number of caps placed in a three-minute period.

Revisions

Several revisions were made in the administration of this test. First, the test period was decreased to two minutes because during pilot-testing a few subjects came close to filling the board in three minutes. This raised the possibility that faster subjects might complete the board before the allotted time had passed and truncate the scoring. Second, the scoring was simplified by recording number of assemblies rather than numbers of rods and numbers of caps. Though the latter was suggested in the original test protocol, it was found to provide no additional information.

Instructions for administration failed to specify the starting position for a subject taking the test. For this study, subjects were instructed to begin with the first rod grasped in the dominant hand and the hand resting on the table beside the board. Finally, the amount of practice allowed to control for learning effects was increased from the recommended "several" assemblies to five two-minute trials.

Washers and Nuts, Dominant Hand

In the washers and nuts test subjects slide washers and nuts in an alternating fashion onto a T-bar mounted on the board. This test can be used to measure the speed of the right, left or both hands. Rather than testing the right and left hands in two separate tests the dominant hand was tested in one test. When subjects stated they were ambidextrous they used either hand. Instructions accompanying the test call for scoring by the total number of washers and nuts placed on a T-bar in 40 seconds.

Revisions

Following pilot testing the allotted time was decreased to 30 seconds because (as with the rods and caps test) some subjects came close to completing the test before the time was up. The starting position was not specified in the instructions. Following pilot testing, subjects were instructed to hold a washer in the dominant hand and rest the hand on the table beside the board. To control for learning effects the recommended practice allowance was increased from "practice a few" to five 30-second trials.

Washers and Nuts, Both Hands

Like the dominant-hand test, this test measures how many washers and nuts can be placed on a T-bar in a given time. The hands work in unison rather than in an alternating fashion -- first placing washers, and then nuts. The right hand places pieces on the right side of the T-bar and the left hand places pieces on the left side.

Revisions

As with the dominant-hand test the length of time allowed was decreased from 40 to 30 seconds, and the amount of practice was increased to five complete trials. The starting position was not originally specified; subjects were instructed to begin with a washer in each hand and both hands resting on the table beside the board.

STEADINESS

The object of this paper and pencil test (Figure 20) is to trace between a pair of narrowly separated lines (1/16 inch) which form a pattern. Two patterns are provided, and the test is scored by the number of segments negotiated without touching the lines. A similar, though shorter, pattern is given for practice.

Revisions

The original instructions were extremely vague. They called for negotiating "segments" of the pattern without defining what a segment is and did not discuss a time limit for the scoring. To standardize the test only one pattern was used; half-inch increments were marked, and every other mark was numbered. Subjects began with a fine-point felt-tip marker on the arrow at the beginning of the pattern, and were scored by the total number of

segments negotiated in 30 seconds minus errors (the number of segments in which lines were crossed). Practice procedures were changed so subjects practiced on the test pattern itself (rather than on a smaller version) and by allowing four trials.

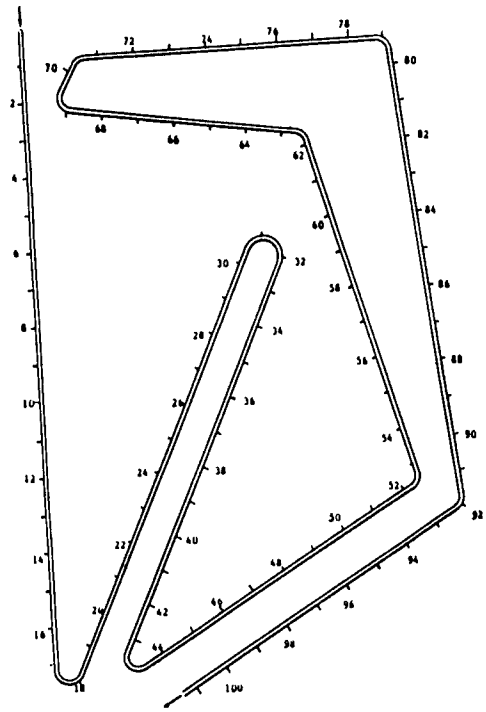

Figure 20. Steadiness pencil and paper test.
(Actual size of the test sheet is 8 1/2" x 11".)

TAPPING TEST

The Tapping Test, which is done on an Apple IIE microcomputer, was designed in an attempt to obtain a "pure" measure of finger speed. The object is to tap a key with the index finger of the dominant hand as many times as possible in a 10-second period. Subjects are given three practice trials.

Revision

The Tapping Test was specifically designed for this study; therefore no revisions were made.

TRACING

The object of this paper and pencil test is to trace through a series of 1/16-inch wide gate-like openings in a maze (Figure 21) without touching any lines. The test is scored by the number of openings negotiated in 50 seconds minus the number of errors (an error was recorded each time the marker touched a line). A similar, though shorter, pattern was provided for practice.

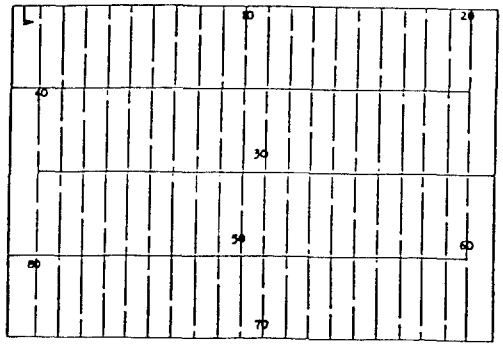

Figure 21. Tracing pencil and paper test.
(Actual size of the test sheet is 8 1/2" x 11".)

Revisions

The time limit was decreased to 30 seconds because some subjects were able to complete the pattern in less than 50 seconds. Test administration was standardized by issuing a fine point marker to all subjects and instructing them to begin with the pen tip in contact with the black arrow at the begining of the maze. Subjects were not allowed to angle the paper in any way. Every 10th gate was numbered to facilitate scoring. The test pattern, rather than the smaller pattern, was used for practice, and the number of practice trials was set at four.

TWO ARM COORDINATION TEST

The Two Arm Coordination Test (Figure 22) measures a subject's ability to move a stylus around a six-point star pattern. The pattern is mounted on a large board with two rod-like handles attached at a pivot point above the board. The stylus is attached on a complex hinge between the two handles. By moving both handles simultaneously, the stylus can be moved around the desired pattern. The test is scored by the number of errors recorded electronically, and by completion time (recorded with a stop watch) for two rotations (clockwise and counterclockwise). Subjects are seated and begin with the stylus at the top center of the pattern. One minute is allowed for practice.

Revision

Several changes were made in the original test design. First, subjects found it difficult to see the pattern while sitting, so the testing position was changed to standing. Second, the starting position of the stylus was changed from the top center of the pattern to the bottom center where the handles were closer together. The scoring procedure was changed from the number of errors to error time because this provided more precise information (a subject could miss a large part of the star and only one error would be recorded). Subjects were scored for error time, and for completion time for one clockwise rotation. One minute of practice proved to be insufficient to control for learning effects, so the amount of practice allowed was increased to twelve complete trials.

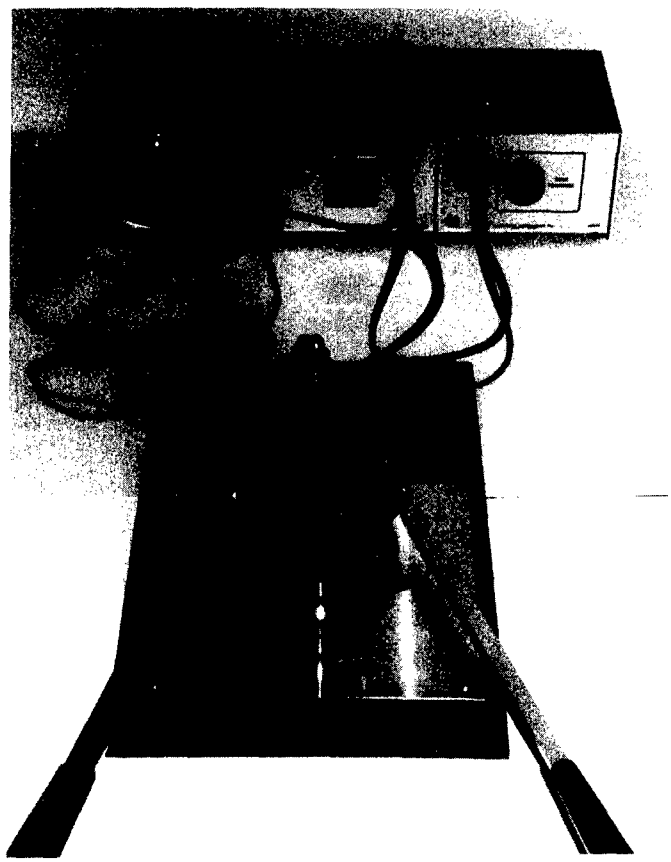

Figure 22. Two Arm Coordination Test.

CHAPTER II

RESULTS

DATA EDITING

Prior to analyses, the data were edited to locate obvious errors. Six measurements were eliminated and six others were combined into three, reducing the 35 measurements to 26 and the 26 tests to 25. The test eliminated was the Numeric Keypad test. It was found to be highly unreliable due to the tendency of some subjects to accidentally punch the return key twice. When this occurs, the number which would have been presented next is skipped and recorded as an error. With numbers varying in length from three to ten digits, two subjects could make the same error (striking the return key twice), while the recorded number of their errors could vary from three to ten.

Two of the other measurements dropped from the analysis were the false start scores and the error scores of the Reaction Time test for which very few numbers other than zero were recorded. The average reaction time for this test was retained.

Finally, preliminary analysis of the data indicated that the "on" and "off" times of the two Photoelectric Rotary Pursuit patterns were perfectly correlated (correlations ranged from -.97 to -.99) so both were not needed. Both "off" times were dropped from the analysis.

Three tests included two measurements: number of errors or error time, and total completion time. The real performance in this instance is not reflected by either of these measured alone but by a combination of them. To effectively use the information the scores must be combined in a meaningful manner. This was done by converting each value to a Z score (which sets the mean to zero and the standard deviation to one) and taking the average of the two scores for each test. Tests in which scoring was converted in this manner were the Two-Arm Coordination, the Mirror Tracer, and the Groove Steadiness tests. Although no literature was found which indicated that this had previously been done for single test scores, this procedure has been used to combine scores from dual-task tests (Rieck et al., 1980, Ackerman et al., 1982) and is "useful for finding averages when differing units of measurement are in use" (Weinberg and Schumaker, 1974).

Table 2 shows sample conversions of the original data to Z scores for two tests: Two Arm Coordination and Mirror Tracer. By averaging the Z scores of both measurements each subject's performance becomes more meaningful and easier to interpret. For example, compare subjects 24 and 26 on the Two-Arm Coordination test. Subject 24 was the slower of the two with a score of 16 seconds but had less error time. The performance of these two subjects -- whose mean scores differ by only .01 -- should be rated as nearly the same yet neither measure by itself indicates this. Subjects 19 and 26 on the other hand completed the test in the same amount of time, but subject 19 had no error while 26 had .30 seconds of error. Clearly subject 19 should have a much better rating and the mean Z-values reflect this. The Mirror Tracer example demonstrates that this procedure is successful for tests which

TABLE 2

Z-SCORE CONVERSIONS

TWO ARM COORDINATION

	Raw Data		Converted Data		
Subject Number	Completion Time (seconds)	Error Time	Completion Time	Error Time	Mean*
18	14.0	0.11	-0.35	-0.36	0.35
19	13.0	0.00	-0.49	-0.71	0.60
20	9.0	0.00	-1.06	-0.71	0.89
21	35.0	0.00	2.65	-0.71	-0.97
22	21.0	0.15	0.65	-0.23	-0.21
23	12.0	0.46	-0.63	0.76	-0.06
24	16.0	0.16	-0.06	-0.20	0.13
25	17.0	0.36	0.08	0.44	-0.26
26	13.0	0.30	-0.49	0.25	0.12
27	10.0	0.25	-0.92	0.09	0.41

MIRROR TRACER

	Raw Data		Converted Data		
Subject Number	Completion Time (seconds)	No. of Errors	Completion Time	No. of Errors	Mean*
55	38	10	-0.40	2.68	-1.14
56	32	4	-0.73	0.56	0.09
57	29	0	-0.90	-0.85	0.88
58	48	0	0.15	-0.85	0.35
59	29	1	-0.71	-0.44	0.57
60	27	2	-0.83	0.08	0.38
61	61	0	1.27	-0.95	-0.16
62	27	0	-0.83	-0.95	0.89
63	21	1	-1.21	-0.44	0.82
64	26	1	-0.90	-0.44	0.67

* Means have been multiplied by -1 for easier interpretation (see text).

are measured in two different units - time and number of errors. Subjects 60 and 62 performed the test in the same amount of time but number 62 had no errors. Subject 62 should have the best score for the Mirror Tracer test and does if the mean Z-score is used. In this instance the number of errors also indicates which is best, although the difference between subject 62 and subject 58 is not reflected in the error score. Neither of these subjects had any errors but subject 58 was much slower. The Z-score mean reflects this relationship as well.

While some of the tests were measured by increments of time, others were measured by pieces placed or assemblies completed. This resulted in smaller numbers indicating "better" scores on some tests, and larger numbers indicating "better" scores on others. In order for the "better" scores to be reflected in the same direction for all tests, the timed test scores were multiplied by -1. This simplified the interpretation of correlation coefficients and factor analysis results. Tests in which scores were converted in this way were the Reaction Time, Minnesota, Two-Arm Coordination, Mirror Tracer, Groove Steadiness and Large and Small Hole Steadiness tests.

SEX DIFFERENCES

T-tests were used to determine if there were any significant differences between males and females. (Raw data were used in these computations because data converted to Z-scores do not yield the needed information.) Means, standard deviations, minimum and maximum values, probability (p) values, and t-test results are presented in Table 3. As can be seen, eight of 26 measurements (Washers and Nuts Both Hands, Tapping, Purdue Assembly, Purdue Pins Both Hands, O'Connor, Photoelectric Square and Circle, and Groove Steadiness) showed significant differences ($p \leq .05$) between males and females.

Table 4 lists 325 male and female correlation coefficients. Differences of .3 or more between the sexes were found on only 13 (or 4%) of the comparisons. These are shown on Table 5.

T-tests and correlations did indicate a few performance differences between males and females. Therefore, the factor analysis was conducted for males and females separately and combined to evaluate the possible differences in the factor patterns. This is discussed further in the following section.

FACTOR ANALYSIS

Factor analysis encompasses a "variety of statistical techniques whose common objective is to represent a set of variables in terms of a smaller number of hypothetical variables" (Kim and Mueller, 1978). This is achieved by "ascertaining the minimum number of hypothetical factors that can account for the observed covariation" (ibid). That is, factor analysis reveals underlying structures by examining the patterns of variance, or, the manner in which variables "load" on a factor. This is done by determining which variables group together (or load highly) on the same factor. Examination of the loading pattern reveals what factors--in this case, skills--the groups of variables seem to represent.

TABLE 3

T-TEST RESULTS

	Mean	Standard Deviation	Minimum	Maximum	p
Rods and Caps					
Males	35.55	6.01	18	47	.4306
Females	36.42	5.87	21	48	
Washers and Nuts, Dominant					
Males	14.28	2.17	10	20	.1384
Females	14.87	2.13	10	19	
Washers and Nuts, Both					
Males	21.05	3.37	14	30	.0056
Females	22.72	3.03	16	32	
Tapping					
Males	72.66	8.45	58	91	.0034
Females	68.43	6.84	47	81	
Purdue Assembly					
Males	45.26	6.27	26	63	.0004
Females	49.02	4.93	39	60	
Purdue Pins, Dominant					
Males	18.57	1.86	15	23	.1193
Females	19.10	1.81	14	23	
Purdue Pins, Both					
Males	14.03	1.35	11	17	.0061
Females	14.78	1.55	12	18	
Reaction Time					
Males	.32	.04	.25	.42	.0767
Females	.34	.05	.26	.49	
Pennsylvania					
Males	36.78	4.43	29	48	.2611
Females	35.87	4.32	26	45	
Screws					
Males	11.24	2.63	6	17	.0549
Females	10.33	2.45	5	17	
Pins and Collars					
Males	44.48	6.73	32	72	.5857
Females	45.20	7.49	29	63	
O'Connor					
Males	46.41	6.43	31	62	.0380
Females	48.78	5.82	38	63	

TABLE 3 (cont'd)

T-TEST RESULTS

	Mean	Standard Deviation	Minimum	Maximum	p
Minnesota					
Males	39.38	4.15	29	47	.6800
Females	39.07	4.07	31	50	
Two Arm Coordination Error Time					
Males	.22	.31	0	1.04	.8432
Females	.24	.42	0	2.07	
Two Arm Coordination Completion Time					
Males	16.42	7.01	7	45	.1242
Females	18.27	5.89	9	36	
Grooved Pegboard					
Males	15.36	1.85	12	19	.4754
Females	15.60	1.76	11	19	
Mirror Tracer, Errors					
Males	2.41	2.83	0	11	.2110
Females	1.85	1.94	0	9	
Mirror Tracer, Completion Time					
Males	45.33	18.14	18	131	.1264
Females	40.47	16.13	15	119	
Photoelectric Square					
Males	21.24	2.70	16.21	27.82	.0004
Females	19.34	2.99	10.87	24.86	
Photoelectric Circle					
Males	26.40	1.76	20.25	28.87	.0001
Females	24.77	2.66	14.64	28.11	
Groove Steadiness Error Time					
Males	.35	.38	0	1.61	.1728
Females	.52	.88	0	6.39	
Groove Steadiness Completion Time					
Males	5.71	3.47	2	21.0	.0019
Females	8.21	4.97	2	27.2	
Tracing					
Males	37.16	8.96	18	57	.3882
Females	35.82	7.81	13	51	

TABLE 3 (cont'd)

T-TEST RESULTS

	Mean	Standard Deviation	Minimum	Maximum	p
Pursuit Aiming II					
Males	112.16	14.24	67	141	.2771
Females	115.35	17.33	61	171	
Medium Tapping					
Males	40.50	5.65	28	55	.5075
Females	39.80	5.78	28	54	
Aiming					
Males	63.22	8.03	50	81	.9247
Females	63.37	8.30	44	86	
Steadiness					
Males	56.03	14.37	27	99	.2409
Females	52.90	14.51	17	89	
Large Holes					
Males	.19	.24	0	1.01	.1307
Females	.13	.20	0	1.05	
Small Holes					
Males	.40	.58	0	2.32	.2931
Females	.56	.97	0	5.66	

TABLE 4

CORRELATION COEFFICIENTS

MALES ABOVE THE DIAGONAL
FEMALES BELOW THE DIAGONAL

	1	2	3	4	5	6	7	8	9	10	11	12	13
1 RODS AND CAPS		.49	.47	.30	.35	.28	.40	.27	.55	.45	.39	.60	.38
2 WASHERS AND NUTS DOMINANT	.27		.53	.21	.35	.45	.53	.13	.45	.42	.33	.53	.36
3 WASHERS AND NUTS BOTH	.28	.69		.44	.36	.48	.50	.26	.61	.44	.50	.50	.53
4 TAPPING	.15	.41	.22		-.05	.17	.06	.11	.35	.24	.20	.20	.39
5 PURDUE ASSEMBLY	.32	.40	.48	.13		.37	.56	.03	.36	.32	.27	.31	.35
6 PURDUE PINS DOMINANT	.53	.47	.55	.32	.38		.57	.31	.34	.31	.23	.37	.43
7 PURDUE PINS BOTH	.40	.53	.66	.23	.61	.56		.26	.40	.43	.11	.54	.41
8 REACTION TIME	-.07	.14	.21	.11	.19	.02	.07		.15	.08	.17	.29	.24
9 PENNSYLVANIA	.43	.39	.50	.19	.40	.43	.56	.23		.49	.52	.50	.44
10 SCREWS	.35	.46	.38	.27	.17	.30	.30	.14	.34		.36	.34	.23
11 PINS AND COLLARS	.20	.46	.33	.16	.22	.24	.15	.23	.14	.22		.15	.18
12 OCONNOR	.44	.46	.49	.21	.35	.43	.45	.17	.43	.29	.42		.39
13 MINNESOTA	.34	.54	.41	.21	.45	.39	.43	.19	.43	.24	.36	.37	
14 TWO ARM COORDINATION	.24	.28	.19	.13	.19	.13	.24	.15	.14	-.01	.31	.31	.40
15 GROOVED PEGBOARD	.41	.47	.49	.28	.38	.54	.45	.21	.41	.35	.23	.40	.34
16 MIRROR TRACER	.10	.15	.20	.18	.12	-.05	.09	.45	.08	.20	.25	.21	.11
17 PHOTOELECTRIC SQUARE	.09	.38	.38	.07	.14	.11	.16	.06	.21	.33	.35	.33	.19
18 PHOTOELECTRIC CIRCLE	.26	.24	.30	.02	.18	.18	.10	.14	.04	.24	.35	.28	.22
19 GROOVE STEADINESS	.09	.15	.21	.12	.14	.19	.01	.03	.01	.13	.32	.14	.27
20 TRACING	.21	.44	.30	.12	.18	.22	.26	.08	.09	.30	.43	.29	.47
21 PURSUIT AIMING II	.17	.46	.48	.18	.21	.31	.29	.07	.34	.35	.32	.44	.43
22 MEDIUM TAPPING	.25	.25	.24	.36	.25	.33	.22	.09	.28	.18	.33	.39	.34
23 AIMING	.23	.52	.47	.37	.21	.33	.26	.04	.31	.25	.50	.43	.46
24 STEADINESS	.43	.30	.29	.28	.12	.27	.21	.10	.25	.38	.40	.36	.35
25 LARGE HOLES	.08	.08	.09	-.07	.12	-.09	-.12	-.20	.07	.01	.14	.08	.02
26 SMALL HOLES	.04	.27	.15	.07	.19	.01	.24	.03	.01	.15	.19	.22	.23

TABLE 4 (CONTINUED)

CORRELATION COEFFICIENTS

MALES ABOVE THE DIAGONAL
FEMALES BELOW THE DIAGONAL

	14	15	16	17	18	19	20	21	22	23	24	25	26
1 RODS AND CAPS	.45	.36	.34	.38	.28	.43	.51	.26	.49	.52	.47	.13	.28
2 WASHERS AND NUTS DOMINANT	.35	.50	.21	.42	.20	.19	.50	.34	.34	.49	.53	.06	.18
3 WASHERS AND NUTS BOTH	.38	.53	.39	.56	.33	.31	.55	.43	.47	.39	.42	.21	.13
4 TAPPING	.35	.25	.27	.32	.38	.18	.28	.12	.42	.21	.23	.09	.16
5 PURDUE ASSEMBLY	.18	.36	.17	.17	.04	.10	.27	.23	.18	.27	.17	-.07	.11
6 PURDUE PINS DOMINANT	.27	.44	-.03	.31	.19	.15	.39	.22	.22	.41	.33	.25	.19
7 PURDUE PINS BOTH	.14	.54	.09	.28	.27	.26	.35	.26	.25	.35	.26	.00	.01
8 REACTION TIME	.13	.20	.06	.30	.26	.18	.27	.16	.23	.33	.29	.20	.16
9 PENNSYLVANIA	.42	.28	.28	.38	.26	.45	.34	.32	.47	.46	.39	.23	.22
10 SCREWS	.30	.28	.33	.25	.23	.29	.10	.10	.29	.33	.25	.07	.30
11 PINS AND COLLARS	.42	.18	.40	.37	.34	.33	.23	.32	.27	.30	.29	.34	.33
12 OCONNOR	.33	.31	.12	.36	.22	.29	.55	.38	.43	.49	.48	-.15	.05
13 MINNESOTA	.39	.36	.24	.44	.32	.20	.48	.34	.45	.35	.23	.00	.09
14 TWO ARM COORDINATION		.35	.37	.42	.41	.39	.51	.41	.41	.48	.41	.04	.32
15 GROOVED PEGBOARD	.30		.26	.40	.25	.22	.45	.38	.31	.37	.32	.11	.02
16 MIRROR TRACER	.08	.05		.42	.42	.37	.27	.19	.37	.40	.32	.19	.00
17 PHOTOELECTRIC SQUARE	.34	.02	.21		.54	.25	.54	.34	.50	.52	.59	.15	.02
18 PHOTOELECTRIC CIRCLE	.35	.06	.16	.58		.40	.40	.19	.38	.33	.28	.10	.24
19 GROOVE STEADINESS	.21	-.06	.20	.44	.44		.29	.26	.12	.33	.28	.16	.06
20 TRACING	.37	.29	.15	.28	.47	.22		.51	.50	.71	.64	.06	.12
21 PURSUIT AIMING II	.12	.43	.08	.39	.34	.29	.55		.43	.55	.35	-.11	.01
22 MEDIUM TAPPING	.00	.11	.23	.13	.20	.34	.39	.51		.54	.52	.04	.12
23 AIMING	.28	.29	.14	.44	.39	.28	.66	.68	.63		.60	.07	.05
24 STEADINESS	.09	.21	.23	.21	.20	.21	.58	.46	.43	.57		.07	.09
25 LARGE HOLES	.18	-.01	-.03	.14	.02	.07	.07	.21	.13	.14	.21		.08
26 SMALL HOLES	.07	.01	.30	.14	.17	-.03	.14	.25	.16	.23	.00	.09	

TABLE 5

DIFFERENCES (GREATER THAN .3) BETWEEN MALES AND FEMALES ON CORRELATION COEFFICIENTS

Correlated Tests	Males	Females	Differences
Pennsylvania/Pins and Collars	.52	.14	.38
Screws/Two Arm Coordination	.30	-.01	.31
Reaction Time/Mirror Tracer	.06	.45	.39
Tapping/Photoelectric-Circle	.38	.02	.36
Rods and Caps/Groove Steadiness	.43	.09	.34
Pennsylvania/Groove Steadiness	.45	.01	.44
Rods and Caps/Tracing	.51	.21	.30
Two Arm Coordination/Medium Tapping	.41	.00	.41
Photoelectric Square/Medium Tapping	.50	.13	.37
Two Arm Coordination/Steadiness	.41	.09	.32
Photoelectric Square/Steadiness	.59	.21	.38
Pursuit Aiming II/Large Holes	-.11	.21	.32
Mirror Tracer/Small Holes	.00	.30	.30

Two factor analysis methods--principal components and maximum likelihood--were used in this study. In principal components, factors are individually extracted; the first accounts for the largest amount of variance, the second accounts for the next largest amount of variance after extraction of the first variable, and so on. In maximum likelihood, the factors which account for the largest amount of variance are extracted as a group. The experimenter specifies the number of factors to be extracted and the computer identifies the combination of factors which controls the greatest amount of variance. A comparison of the results yielded by these two factor analysis techniques for males vs. females vs. all subjects provided an indication of the stability of the factor pattern.

A standard practice in factor analysis is to rotate the patterns. By rotating the reference axis while the data points remain fixed, the results can be simplified. A varimax rotation program, which maximizes the variance in each column of the matrix, was used. This facilitates interpretation of the factors by maximizing the higher loading tests and minimizing the lower ones.

Tables 6 through 11 are the results of the six factor analysis matrices. Though a few differences were revealed, their overall agreement indicates a stable pattern. In most cases the six matrices differed only in the order of presentation of the seven factors. For example, tests which loaded highly and together on the first factor for one method (principal components or maximum likelihood) and group (males, females and mixed) were found in a few cases to load highly and together on the third factor for a different method or group. This means that the proportion of the total variance accounted for by each of the factors was not the same across all methods or groups. To demonstrate the general agreement, the six factor analysis matrices were integrated and reorganized by test loading patterns rather than by amount of variance controlled. These integrated data are shown on Tables 12 through 18. The original source (i.e. method and group) for each pattern is given and, to facilitate interpretation, only tests which loaded highly (.3 or above) are shown.

A representative test was selected from each of the loading patterns. In this way, the test battery was reduced from 26 to seven tests without compromising its effectiveness in measuring a variety of skills. When more than one test had a fairly high loading (.3 or above) on a given factor, the test chosen to represent that factor was selected by considering durability and availability of the equipment, as well as ease of administration, and reliability of the test. Each of the factors and the test selected to represent it are discussed individually below.

Table 12. Loading pattern I (which accounts for the greatest amount of variance) appears to represent a general manual dexterity skill. The tests which load on this factor (except for Screws and Pursuit Aiming II, both of which had only moderate load levels) involve direct manipulation of parts by the hands (rather than by tools). This pattern is found consistently across all six matrices. Tests which represent this factor are the three subtests of the Roeder Manipulative Aptitude Test (Rods and Caps, and Washers and Nuts by dominant and both hands), the three Purdue Pegboard tests (Assembly and Pin Placement by dominant and both hands) the Pennsylvania, the Crawford Screws, the O'Connor, the Minnesota, and the Grooved Pegboard tests. Of these, the

TABLE 6

PRINCIPAL COMPONENTS
VARIMAX ROTATION FACTOR PATTERN

MALES (N=58) AND FEMALES (N=60)

	FACTOR1	FACTOR2	FACTOR3	FACTOR4	FACTOR5	FACTOR6	FACTOR7
RODS AND CAPS	0.50	0.21	0.15	0.40	-.02	0.20	-.05
WASHERS AND NUTS DOMINANT	0.63	0.32	0.15	0.18	-.01	0.07	0.21
WASHERS AND NUTS BOTH	0.71	0.22	0.17	0.15	0.16	0.20	0.03
TAPPING	0.03	0.21	0.15	0.71	0.09	-.13	0.01
PURDUE ASSEMBLY	0.75	0.00	-.02	-.19	0.11	0.13	0.13
PURDUE PINS DOMINANT	0.70	0.15	0.09	0.17	-.14	0.04	-.10
PURDUE PINS BOTH	0.86	0.05	0.00	0.06	0.01	-.07	0.08
REACTION TIME	0.12	0.07	0.11	0.05	0.80	-.18	-.07
PENNSYLVANIA	0.51	0.16	0.08	0.47	0.14	0.19	-.04
SCREWS	0.31	0.03	0.17	0.65	0.09	0.08	0.21
PINS AND COLLARS	0.23	0.24	0.35	0.04	0.26	0.47	0.24
OCONNOR	0.59	0.38	0.09	0.12	0.10	-.02	0.03
MINNESOTA	0.53	0.31	0.27	0.09	0.10	-.11	0.09
TWO ARM COORDINATION	0.28	0.17	0.60	0.01	0.04	0.04	0.07
GROOVED PEGBOARD	0.65	0.19	0.08	0.12	0.09	-.06	-.11
MIRROR TRACER	0.03	0.13	0.17	0.17	0.70	0.23	0.17
PHOTOELECTRIC SQUARE	0.06	0.27	0.68	0.26	0.11	0.03	0.05
PHOTOELECTRIC CIRCLE	-.03	0.16	0.79	0.19	0.09	-.10	0.15
GROOVE STEADINESS	0.10	0.11	0.64	0.03	0.11	0.26	-.18
TRACING	0.26	0.72	0.38	0.00	0.02	-.07	0.04
PURSUIT AIMING II	0.33	0.68	0.17	-.11	-.01	0.03	0.12
MEDIUM TAPPING	0.14	0.69	0.04	0.32	0.17	0.08	0.04
AIMING	0.27	0.77	0.26	0.11	0.04	0.09	0.08
STEADINESS	0.14	0.69	0.14	0.30	0.12	0.15	-.12
LARGE HOLES	0.02	0.05	0.03	0.00	-.06	0.85	-.01
SMALL HOLES	0.06	0.08	0.07	0.10	0.06	0.03	0.92
PERCENTAGE OF VARIANCE EXPLAINED	18.45	12.79	9.71	7.06	5.43	5.11	4.55
CUMULATIVE VARIANCE	18.45	31.24	40.95	48.01	53.44	58.55	63.10

TABLE 7

PRINCIPAL COMPONENTS
VARIMAX ROTATION FACTOR PATTERN

MALES (N=58)

	FACTOR1	FACTOR2	FACTOR3	FACTOR4	FACTOR5	FACTOR6	FACTOR7
RODS AND CAPS	0.38	0.32	0.15	0.52	0.31	-.09	0.18
WASHERS AND NUTS DOMINANT	0.45	0.57	0.06	0.14	0.18	0.01	0.05
WASHERS AND NUTS BOTH	0.33	0.57	0.43	0.20	0.07	0.24	0.01
TAPPING	0.07	0.04	0.82	0.09	0.17	-.01	0.02
PURDUE ASSEMBLY	0.15	0.73	-.11	0.11	0.10	-.02	-.22
PURDUE PINS DOMINANT	0.19	0.66	0.12	-.13	0.17	0.22	0.39
PURDUE PINS BOTH	0.09	0.83	0.07	0.22	-.11	-.12	0.24
REACTION TIME	0.20	0.08	0.12	0.09	0.05	0.15	0.76
PENNSYLVANIA	0.27	0.42	0.22	0.47	0.31	0.11	-.02
SCREWS	-.02	0.46	0.16	0.53	0.35	-.01	-.07
PINS AND COLLARS	0.30	0.16	0.09	0.35	0.42	0.54	-.18
OCONNOR	0.44	0.44	0.10	0.32	0.08	-.40	0.29
MINNESOTA	0.25	0.47	0.58	-.01	0.02	-.07	0.06
TWO ARM COORDINATION	0.54	0.07	0.34	0.23	0.35	0.06	-.11
GROOVED PEGBOARD	0.31	0.60	0.26	0.02	-.17	0.17	0.02
MIRROR TRACER	0.29	0.00	0.35	0.56	-.15	0.30	-.29
PHOTOELECTRIC SQUARE	0.54	0.18	0.45	0.18	-.12	0.24	0.14
PHOTOELECTRIC CIRCLE	0.22	-.02	0.59	0.35	0.03	0.14	0.19
GROOVE STEADINESS	0.17	0.07	0.09	0.76	-.04	0.10	0.14
TRACING	0.77	0.24	0.25	0.04	0.01	-.01	0.21
PURSUIT AIMING II	0.73	0.22	0.06	-.01	-.01	-.02	-.16
MEDIUM TAPPING	0.55	0.14	0.48	0.13	0.12	-.08	0.02
AIMING	0.76	0.22	0.08	0.27	0.02	0.03	0.17
STEADINESS	0.72	0.13	0.08	0.22	0.06	0.04	0.23
LARGE HOLES	-.07	0.05	0.03	0.11	0.05	0.83	0.25
SMALL HOLES	0.02	0.02	0.11	0.01	0.88	0.07	0.10
PERCENTAGE OF VARIANCE EXPLAINED	16.81	14.80	9.80	9.27	6.16	5.90	5.40
CUMULATIVE VARIANCE	16.81	31.61	41.41	50.68	56.84	62.74	68.14

TABLE 8

PRINCIPAL COMPONENTS
VARIMAX ROTATION FACTOR PATTERN

FEMALES (N=60)

	FACTOR1	FACTOR2	FACTOR3	FACTOR4	FACTOR5	FACTOR6	FACTOR7
RODS AND CAPS	0.62	0.20	0.10	0.03	0.04	-.43	0.25
WASHERS AND NUTS DOMINANT	0.57	0.36	0.20	-.02	0.19	0.37	-.23
WASHERS AND NUTS BOTH	0.71	0.20	0.30	0.03	0.04	0.25	-.12
TAPPING	0.23	0.48	-.09	0.15	-.07	-.02	-.35
PURDUE ASSEMBLY	0.68	-.02	0.04	0.16	0.18	0.14	0.21
PURDUE PINS DOMINANT	0.71	0.26	0.09	-.14	0.01	-.22	-.18
PURDUE PINS BOTH	0.83	0.05	0.01	-.01	0.08	0.19	-.09
REACTION TIME	0.11	0.00	0.01	0.76	0.20	0.02	-.30
PENNSYLVANIA	0.74	0.14	0.00	0.11	-.07	-.05	0.08
SCREWS	0.43	0.30	0.32	0.09	-.31	0.06	-.22
PINS AND COLLARS	0.14	0.44	0.30	0.27	0.35	0.09	0.06
OCONNOR	0.56	0.31	0.19	0.19	0.13	0.05	0.16
MINNESOTA	0.46	0.37	0.07	0.09	0.43	0.10	0.01
TWO ARM COORDINATION	0.19	0.02	0.25	0.06	0.81	-.04	0.09
GROOVED PEGBOARD	0.64	0.23	-.13	-.02	0.29	-.05	-.26
MIRROR TRACER	0.04	0.15	0.17	0.82	-.08	0.15	0.04
PHOTOELECTRIC SQUARE	0.15	0.11	0.83	0.02	0.06	0.20	0.03
PHOTOELECTRIC CIRCLE	0.08	0.15	0.78	0.06	0.24	0.02	0.00
GROOVE STEADINESS	-.01	0.22	0.68	0.13	0.04	-.19	0.08
TRACING	0.09	0.66	0.26	-.05	0.44	0.10	-.07
PURSUIT AIMING II	0.29	0.65	0.27	-.13	0.04	0.29	0.03
MEDIUM TAPPING	0.18	0.73	0.06	0.19	-.13	-.03	0.20
AIMING	0.20	0.79	0.27	-.06	0.19	0.20	0.00
STEADINESS	0.18	0.75	0.12	0.12	0.00	-.22	0.14
LARGE HOLES	0.01	0.18	0.04	-.14	0.08	0.12	0.76
SMALL HOLES	0.13	0.11	0.03	0.19	-.01	0.75	0.20
PERCENTAGE OF VARIANCE EXPLAINED	18.88	14.71	9.64	6.24	6.20	5.31	4.89
CUMULATIVE VARIANCE	18.88	33.59	43.23	49.47	55.67	60.98	65.87

TABLE 9

MAXIMUM LIKELIHOOD
VARIMAX ROTATION FACTOR PATTERN

MALES (N=58) AND FEMALES (N=60)

	FACTOR1	FACTOR2	FACTOR3	FACTOR4	FACTOR5	FACTOR6	FACTOR7
RODS AND CAPS	0.41	0.20	0.12	0.07	0.17	0.86	0.00
WASHERS AND NUTS DOMINANT	0.62	0.29	0.16	0.13	0.25	0.00	-.13
WASHERS AND NUTS BOTH	0.70	0.20	0.23	0.12	0.28	-.03	-.01
TAPPING	0.09	0.15	0.21	0.96	-.01	0.06	0.01
PURDUE ASSEMBLY	0.65	0.06	0.01	-.15	0.07	0.07	0.07
PURDUE PINS DOMINANT	0.64	0.16	0.10	0.08	0.01	0.11	0.00
PURDUE PINS BOTH	0.88	0.06	0.06	-.04	-.10	0.05	0.05
REACTION TIME	0.11	0.10	0.24	0.08	0.10	-.06	0.01
PENNSYLVANIA	0.49	0.15	0.18	0.19	0.26	0.20	0.21
SCREWS	0.32	0.06	0.29	0.19	0.21	0.18	0.07
PINS AND COLLARS	0.20	0.22	0.36	0.04	0.51	0.03	0.00
OCONNOR	0.54	0.33	0.13	0.01	0.11	0.23	0.09
MINNESOTA	0.47	0.34	0.19	0.16	0.06	0.07	-.03
TWO ARM COORDINATION	0.21	0.26	0.30	0.12	0.18	0.15	-.25
GROOVED PEGBOARD	0.58	0.20	0.08	0.14	0.07	0.09	-.17
MIRROR TRACER	0.07	0.15	0.27	0.13	0.31	0.06	0.08
PHOTOELECTRIC SQUARE	0.10	0.27	0.62	0.09	0.19	-.02	-.04
PHOTOELECTRIC CIRCLE	-.03	0.15	0.96	0.01	-.14	0.13	-.10
GROOVE STEADINESS	0.08	0.17	0.41	0.01	0.19	0.09	0.07
TRACING	0.24	0.78	0.29	0.03	-.01	0.08	-.31
PURSUIT AIMING II	0.33	0.56	0.22	-.04	0.14	-.10	0.13
MEDIUM TAPPING	0.17	0.58	0.23	0.24	0.06	0.14	0.42
AIMING	0.28	0.71	0.28	0.09	0.18	0.05	0.08
STEADINESS	0.16	0.62	0.17	0.12	0.21	0.21	-.03
LARGE HOLES	0.02	0.03	0.04	-.03	0.37	0.04	-.02
SMALL HOLES	0.11	0.06	0.23	0.06	0.08	0.02	0.03
PERCENTAGE OF VARIANCE EXPLAINED	16.45	11.26	9.61	4.76	4.04	4.03	1.91
CUMULATIVE VARIANCE	16.45	27.71	37.32	42.08	46.12	50.15	52.06

TABLE 10

MAXIMUM LIKELIHOOD
VARIMAX ROTATION FACTOR PATTERN

MALES (N=58)

	FACTOR1	FACTOR2	FACTOR3	FACTOR4	FACTOR5	FACTOR6	FACTOR7
RODS AND CAPS	0.47	0.29	0.52	0.02	0.10	0.17	-.10
WASHERS AND NUTS DOMINANT	0.45	0.47	0.25	0.00	0.14	0.02	0.04
WASHERS AND NUTS BOTH	0.35	0.44	0.19	0.06	0.76	0.14	0.21
TAPPING	0.23	-.05	0.24	0.23	0.39	0.08	0.04
PURDUE ASSEMBLY	0.15	0.57	0.16	-.09	0.01	0.10	0.05
PURDUE PINS DOMINANT	0.32	0.56	0.13	0.08	0.09	-.31	0.29
PURDUE PINS BOTH	0.14	0.96	0.06	0.18	0.05	0.01	-.14
REACTION TIME	0.28	0.20	0.10	0.18	0.06	-.12	0.08
PENNSYLVANIA	0.30	0.33	0.57	0.00	0.29	0.15	0.06
SCREWS	0.06	0.41	0.52	0.03	0.11	0.26	0.07
PINS AND COLLARS	0.19	0.09	0.49	0.12	0.23	0.23	0.44
OCONNOR	0.50	0.40	0.31	0.01	0.23	-.04	-.40
MINNESOTA	0.38	0.32	0.12	0.16	0.29	0.01	0.01
TWO ARM COORDINATION	0.51	0.03	0.36	0.20	0.08	0.13	0.13
GROOVED PEGBOARD	0.35	0.51	-.05	0.11	0.19	0.10	0.15
MIRROR TRACER	0.27	0.03	0.12	0.18	0.15	0.75	0.18
PHOTOELECTRIC SQUARE	0.54	0.15	0.07	0.33	0.28	0.20	0.15
PHOTOELECTRIC CIRCLE	0.24	0.06	0.19	0.92	0.13	0.17	0.06
GROOVE STEADINESS	0.22	0.17	0.32	0.24	0.06	0.27	0.03
TRACING	0.83	0.20	0.01	0.18	0.21	-.04	0.00
PURSUIT AIMING II	0.55	0.18	0.03	0.01	0.18	0.06	0.01
MEDIUM TAPPING	0.54	0.12	0.23	0.16	0.22	0.18	-.07
AIMING	0.80	0.23	0.17	0.08	-.09	0.18	0.06
STEADINESS	0.70	0.15	0.16	0.05	0.08	0.10	0.03
LARGE HOLES	0.01	0.05	0.12	0.03	0.06	0.06	0.52
SMALL HOLES	0.04	-.02	0.51	0.17	0.01	-.20	0.21
PERCENTAGE OF VARIANCE EXPLAINED	17.74	12.08	8.10	5.31	5.27	4.53	3.68
CUMULATIVE VARIANCE	17.74	29.82	37.92	43.23	48.50	53.03	56.71

TABLE II

MAXIMUM LIKELIHOOD
VARIMAX ROTATION FACTOR PATTERN

FEMALES (N=60)

	FACTOR1	FACTOR2	FACTOR3	FACTOR4	FACTOR5	FACTOR6	FACTOR7
RODS AND CAPS	0.40	0.11	0.06	-.06	0.06	0.90	0.10
WASHERS AND NUTS DOMINANT	0.66	0.41	0.20	0.02	-.04	-.06	0.06
WASHERS AND NUTS BOTH	0.77	0.26	0.22	0.09	-.04	-.07	-.05
TAPPING	0.29	0.20	0.00	0.05	0.26	-.01	0.06
PURDUE ASSEMBLY	0.62	0.01	0.04	0.10	0.13	0.07	0.07
PURDUE PINS DOMINANT	0.65	0.16	0.00	-.05	0.14	0.26	-.03
PURDUE PINS BOTH	0.82	0.05	0.02	-.05	0.05	0.05	0.07
REACTION TIME	0.14	0.06	-.01	0.98	-.01	-.09	0.09
PENNSYLVANIA	0.64	0.03	0.11	0.16	0.12	0.19	-.02
SCREWS	0.36	0.29	0.25	0.12	-.07	0.21	-.21
PINS AND COLLARS	0.20	0.44	0.25	0.17	0.11	0.05	0.15
OCONNOR	0.51	0.22	0.23	0.10	0.19	0.20	0.13
MINNESOTA	0.47	0.38	0.05	0.09	0.13	0.09	0.25
TWO ARM COORDINATION	0.19	0.14	0.24	0.03	-.05	0.06	0.94
GROOVED PEGBOARD	0.60	0.27	-.14	0.11	-.11	0.16	0.17
MIRROR TRACER	0.06	0.11	0.20	0.45	0.14	0.08	0.00
PHOTOELECTRIC SQUARE	0.17	0.16	0.95	0.02	-.06	-.06	0.06
PHOTOELECTRIC CIRCLE	0.07	0.30	0.55	0.11	0.01	0.18	0.15
GROOVE STEADINESS	0.03	0.15	0.45	0.02	0.27	0.01	0.10
TRACING	0.14	0.78	0.14	0.00	0.09	0.04	0.22
PURSUIT AIMING II	0.35	0.60	0.26	0.00	0.23	-.07	-.08
MEDIUM TAPPING	0.20	0.36	0.10	0.07	0.89	0.09	-.08
AIMING	0.28	0.70	0.31	-.05	0.34	-.02	0.08
STEADINESS	0.14	0.64	0.12	0.08	0.13	0.33	-.08
LARGE HOLES	-.03	0.13	0.14	-.22	0.11	0.03	0.16
SMALL HOLES	0.18	0.15	0.10	-.01	0.07	-.07	0.00
PERCENTAGE OF VARIANCE EXPLAINED	17.60	11.82	7.87	5.29	5.07	4.74	4.74
CUMULATIVE VARIANCE	17.60	29.42	37.29	42.58	47.65	52.39	57.13

TABLE 12

LOADING PATTERN I

METHOD*	PC	PC	PC	ML	ML	ML
SAMPLE	ALL	MALES	FEMALES	ALL	MALES	FEMALES
ORDER OF APPEARANCE	1	2	1	1	2	1
RODS AND CAPS	.50	.32	.62	.41		.40
WASHERS AND NUTS DOMINANT	.63	.57	.57	.62	.47	.66
WASHERS AND NUTS BOTH	.71	.57	.71	.70	.44	.77
TAPPING						
PURDUE ASSEMBLY	.75	.73	.68	.65	.57	.62
PURDUE PINS DOMINANT	.70	.66	.71	.64	.56	.65
PURDUE PINS BOTH	.86	.83	.83	.88	.96	.82
REACTION TIME						
PENNSYLVANIA	.51	.42	.74	.49	.33	.64
SCREWS	.31	.46	.43	.32	.41	.36
PINS AND COLLARS						
OCONNOR	.59	.44	.56	.54	.40	.51
MINNESOTA	.53	.47	.46	.47	.32	.47
TWO ARM COORDINATION						
GROOVED PEGBOARD	.65	.60	.64	.58	.51	.60
MIRROR TRACER						
PHOTOELECTRIC SQUARE						
PHOTOELECTRIC CIRCLE						
GROOVE STEADINESS						
TRACING						
PURSUIT AIMING II	.33			.33		.35
MEDIUM TAPPING						
AIMING						
STEADINESS						
LARGE HOLES						
SMALL HOLES						

* PC = PRINCIPAL COMPONENTS
  ML = MAXIMUM LIKELIHOOD

Purdue Assembly test was chosen for the final battery for several reasons: the equipment is highly durable, easy to transport, and easily obtainable; the test has been widely used in other studies and is easy to standardize. Though the Pins (both hands) test had higher loadings, the Assembly task should be more sensitive to drug conditions because it is more difficult (subjects must assemble rather than just place pieces). This test has been shown to be a very sensitive measure of differences in performance between subjects wearing different types of chemical defense gloves (Ross et al, in press).

Table 13. Loading pattern II is consistently represented by the paper and pencil tests (Tracing, Pursuit Aiming II, Medium Tapping, Aiming and Steadiness) on all six matrices. These tests involve using pens or pencils to place marks or draw lines accurately and steadily, and so seem representative of the aiming ability defined in Table 1. Of these tests the Tracing test and Aiming test results were very similar. Aiming was selected as it was easier to adiminister.

Table 14. Loading pattern III appeared to represent a movement steadiness skill or control precision as indicated by the tests which consistently load on the six matrices--both patterns of the Photoelectric Rotary Pursuit (Circle and Square), Two Arm Coordination and Groove Steadiness. The latter two tests were eliminated from consideration: the Two Arm Coordination because it required an extensive number of practices (12) to control for learning effects, and the Groove Steadiness test because it was difficult to standarize subject techniques (some subjects concentrated on accuracy, and others on speed). Of the two Photoelectric patterns the Circle pattern was chosen for the battery because, overall, it had higher loadings, and because it is an easier pattern to follow, which may provide a purer measure of the skill. (Since the light underneath the pattern moves in a circle, it appears to move more quickly around the corners of the square pattern. This forced subjects to speed up and slow down to follow the light successfully.)

Table 15. Loading pattern IV, which appears in four of the six matrices, is not as easily interpretable as previous patterns because it does not appear as consistently as the others and it is represented by two tests which do not appear to have any similarities. The Mirror Tracer test requires subjects to trace between two patterns while looking at the inverted, reversed mirror image. Because it requires a larger number of practice trials (12) and does not seem to represent any real-life trade or skills it was dropped from battery consideration. The Reaction Time test, which is computerized, was retained because it appears to be the only test of the original twenty-six that provides a simple measure of the speed of response to a stimulus.

Table 16. Two tests load fairly consistently on loading pattern V - the Pins and Collars and the Large Hole Steadiness test. The relationship between these two tests is not immediately obvious but they both require subjects to hold small tools steadily. This was thus classified as a steadiness ability. Of the two, the Large Hole Steadiness test loads more highly and more consistently, and was retained for the battery.

Table 17. Though several apparatus tests load somewhat sporadically in loading pattern VI no particular skill clearly emerges. As noted earlier, factor loading becomes less stable as the amount of variance accounted for

TABLE 13

LOADING PATTERN II

METHOD*	PC	PC	PC	ML	ML	ML
SAMPLE	ALL	MALES	FEMALES	ALL	MALES	FEMALES
ORDER OF APPEARANCE	2	1	2	1	1	1
RODS AND CAPS		.38			.47	
WASHERS AND NUTS DOMINANT	.32	.45	.36		.45	.41
WASHERS AND NUTS BOTH		.33			.35	
TAPPING			.48			
PURDUE ASSEMBLY						
PURDUE PINS DOMINANT					.32	
PURDUE PINS BOTH						
REACTION TIME						
PENNSYLVANIA					.30	
SCREWS			.30			
PINS AND COLLARS		.30	.44			.44
OCONNOR	.38	.44	.31	.33	.50	
MINNESOTA	.31		.37	.34	.38	.38
TWO ARM COORDINATION		.54			.51	
GROOVED PEGBOARD		.31			.35	
MIRROR TRACER						
PHOTOELECTRIC SQUARE		.54			.54	
PHOTOELECTRIC CIRCLE						.30
GROOVE STEADINESS						
TRACING	.72	.77	.66	.78	.83	.78
PURSUIT AIMING II	.68	.73	.65	.56	.55	.60
MEDIUM TAPPING	.69	.55	.73	.58	.54	.36
AIMING	.77	.76	.79	.71	.80	.70
STEADINESS	.69	.72	.75	.62	.70	.64
LARGE HOLES						
SMALL HOLES						

* PC = PRINCIPAL COMPONENTS
  ML = MAXIMUM LIKELIHOOD

TABLE 14

LOADING PATTERN III

METHOD*	PC	PC	PC	ML	ML	ML
SAMPLE	ALL	MALES	FEMALES	ALL	MALES	FEMALES
ORDER OF APPEARANCE	3	3	3	3	4	3
RODS AND CAPS						
WASHERS AND NUTS DOMINANT						
WASHERS AND NUTS BOTH		.43	.30			
TAPPING		.82				
PURDUE ASSEMBLY						
PURDUE PINS DOMINANT						
PURDUE PINS BOTH						
REACTION TIME						
PENNSYLVANIA						
SCREWS			.32			
PINS AND COLLARS	.35		.30	.36		
OCONNOR						
MINNESOTA		.58				
TWO ARM COORDINATION	.60	.34		.30		
GROOVED PEGBOARD						
MIRROR TRACER		.35				
PHOTOELECTRIC SQUARE	.68	.45	.83	.62	.33	.95
PHOTOELECTRIC CIRCLE	.79	.59	.78	.96	.92	.55
GROOVE STEADINESS	.64		.68	.41		.45
TRACING	.38					
PURSUIT AIMING II						
MEDIUM TAPPING		.48				
AIMING						.31
STEADINESS						
LARGE HOLES						
SMALL HOLES						

* PC = PRINCIPAL COMPONENTS
  ML = MAXIMUM LIKELIHOOD

TABLE 15

LOADING PATTERN IV

METHOD*	PC	PC	PC	ML
SAMPLE	ALL	MALES	FEMALES	FEMALES
ORDER OF APPEARANCE	5	7	4	4
RODS AND CAPS				
WASHERS AND NUTS DOMINANT				
WASHERS AND NUTS BOTH				
TAPPING				
PURDUE ASSEMBLY				
PURDUE PINS DOMINANT		.39		
PURDUE PINS BOTH				
REACTION TIME	.80	.76	.76	.98
PENNSYLVANIA				
SCREWS				
PINS AND COLLARS				
OCONNOR				
MINNESOTA				
TWO ARM COORDINATION				
GROOVED PEGBOARD				
MIRROR TRACER	.70		.82	.45
PHOTOELECTRIC SQUARE				
PHOTOELECTRIC CIRCLE				
GROOVE STEADINESS				
TRACING				
PURSUIT AIMING II				
MEDIUM TAPPING				
AIMING				
STEADINESS				
LARGE HOLES				
SMALL HOLES				

* PC = PRINCIPAL COMPONENTS
  ML = MAXIMUM LIKELIHOOD

TABLE 16

LOADING PATTERN V

METHOD*	PC	PC	PC	ML	ML
SAMPLE	ALL	MALES	FEMALES	ALL	MALES
ORDER OF APPEARANCE	6	6	7	5	7
RODS AND CAPS					
WASHERS AND NUTS DOMINANT					
WASHERS AND NUTS BOTH					
TAPPING					
PURDUE ASSEMBLY					
PURDUE PINS DOMINANT					
PURDUE PINS BOTH					
REACTION TIME					
PENNSYLVANIA					
SCREWS					
PINS AND COLLARS	.47	.54		.51	.44
OCONNOR					
MINNESOTA					
TWO ARM COORDINATION					
GROOVED PEGBOARD					
MIRROR TRACER		.30		.31	
PHOTOELECTRIC SQUARE					
PHOTOELECTRIC CIRCLE					
GROOVE STEADINESS					
TRACING					
PURSUIT AIMING II					
MEDIUM TAPPING					
AIMING					
STEADINESS					
LARGE HOLES	.85	.83	.76	.37	.52
SMALL HOLES					

* PC = PRINCIPAL COMPONENTS
  ML = MAXIMUM LIKELIHOOD

TABLE 17

LOADING PATTERN VI

METHOD*	PC	PC	PC	ML
SAMPLE	MALES	MALES	FEMALES	MALES
ORDER OF APPEARANCE	7	5	6	3
RODS AND CAPS		.31		.52
WASHERS AND NUTS DOMINANT			.37	
WASHERS AND NUTS BOTH				
TAPPING				
PURDUE ASSEMBLY				
PURDUE PINS DOMINANT				
PURDUE PINS BOTH				
REACTION TIME				
PENNSYLVANIA		.31		.57
SCREWS		.35		.52
PINS AND COLLARS		.42		.49
OCONNOR				.31
MINNESOTA				
TWO ARM COORDINATION		.35		.36
GROOVED PEGBOARD				
MIRROR TRACER				
PHOTOELECTRIC SQUARE				
PHOTOELECTRIC CIRCLE				
GROOVE STEADINESS				.32
TRACING				
PURSUIT AIMING II				
MEDIUM TAPPING				
AIMING				
STEADINESS				
LARGE HOLES				
SMALL HOLES	.92	.88	.75	.51

* PC = PRINCIPAL COMPONENTS
  ML = MAXIMUM LIKELIHOOD

decreases. This makes the results difficult to interpret. The Small Holes Steadiness test, however, seems to be the best representative of this factor in terms of consistency and degree of loading. Thus, it is assumed that this factor also represents a steadiness ability, differing from the Large Hole Steadiness test (Table 14) in that it is a "finer" measure.

Table 18. Loading Pattern VII seems to be a combination of residual variance. The Tapping test, however, consistently appears with high loadings. Because of this, and because this test seems to be the purest measure of speed in the original set of tests, it was included in the final battery.

TABLE 18

LOADING PATTERN VII

METHOD*	PC	PC	PC	ML	ML
SAMPLE	ALL	MALES	FEMALES	ALL	MALES
ORDER OF APPEARANCE	4	3	2	4	5
RODS AND CAPS	.40				
WASHERS AND NUTS DOMINANT			.36		
WASHERS AND NUTS BOTH		.43			.76
TAPPING	.71	.82	.48	.96	.39
PURDUE ASSEMBLY					
PURDUE PINS DOMINANT					
PURDUE PINS BOTH					
REACTION TIME					
PENNSYLVANIA	.47				
SCREWS	.65		.30		
PINS AND COLLARS			.44		
OCONNOR			.31		
MINNESOTA		.58	.37		
TWO ARM COORDINATION		.34			
GROOVED PEGBOARD					
MIRROR TRACER		.35			
PHOTOELECTRIC SQUARE		.45			
PHOTOELECTRIC CIRCLE		.59			
GROOVE STEADINESS					
TRACING			.66		
PURSUIT AIMING II			.65		
MEDIUM TAPPING	.32	.48	.73		
AIMING			.79		
STEADINESS	.30		.75		
LARGE HOLES					
SMALL HOLES					

* PC = PRINCIPAL COMPONENTS
  ML = MAXIMUM LIKELIHOOD

CONCLUSIONS

The seven tests selected for the final battery are:

Purdue Pegboard - Assembly
Aiming
Photoelectric Rotary Pursuit - Circle
Reaction Time
Large Holes Steadiness
Small Holes Steadiness
Tapping

These tests appear to represent six of eight abilities identified prior to data collection (Table 1). The two skills which did not emerge in the data analysis were multilimb coordination and finger tactility. Common sense dictates that these abilities must be involved at least in some of the desirable tests. Failure to identify them probably means that they are so well integrated with other skills that they cannot be partialed out.

Except for the first two tests, these tests are, or could be, adapted for administration by a computer. It should be noted that while a test of steadiness should be included in this battery, the tests that were reviewed (Groove Steadiness and Nine-Hole Steadiness) were selected because they were readily obtainable, not because they were necessarily the best. Though several revisions were made to both tests in an attempt to standardize them, their reliability is still questionable. Continued attention to the search for or development of a more standardized steadiness test is recommended.

APPENDIX A

TESTS ELIMINATED FROM BATTERY CONSIDERATION

In addition to the Pennsylvania Bi-Manual Worksample disassembly task and the triangle pattern of the Rotary Pursuit task, the following tests were eliminated from battery consideration after evaluation. Reasons for exclusion from the battery include: difficulty in controlling for learning effects, difficulty of standardizing administration, inconsistent and inaccurate scoring mechanisms, and measurement of irrelevant skills.

HAND-TOOL DEXTERITY TEST

The Hand-Tool Dexterity Test is often referred to as the Bennett Test, after its creator. The test consists of a large wooden frame in which four nut, bolt and washer assemblies of three different sizes are assembled in three rows with the largest at the top and the smallest at the bottom. The task is to remove the assemblies in a specified order and reassemble them into the other side of the wood frame. Large tools (screwdriver, two open-ended wrenches and an adjustable wrench) are used to assemble and disassemble the nut and bolt combinations. The frame is placed so that subjects work from left to right.

The Bennett test is scored by the length of time needed to disassemble and reassemble all 12 nut and bolt combinations. Compared to other dexterity tests, the Bennett Test is rather long in terms of time needed for completion. During pilot testing, subjects' scores ranged from almost five minutes to over nine minutes. The test was reduced by half but other problems were encountered as well. One of these was the difficulty of standardizing the tightness of the nut/bolt assemblies which was likely to affect subjects' scores. Previous experience with large tools also seemed to greatly affect scores. In fact, the test manual states that the Bennett is a "combination of aptitude and of achievement based on past experience in handling tools" (Bennett, 1981). Scores are also affected by the need to retrieve parts or tools dropped during the test. In other dexterity tests, there are sufficient numbers of surplus parts so that subjects can disregard dropped parts and continue. Because subjects' scores can vary so greatly under normal conditions, this test is unlikely to be sensitive to CD treatment drugs.

INFRARED TARGET PISTOL

The Infrared Target Pistol looks very much like a U.S. government .45 caliber pistol. When the trigger is squeezed it emits a shot burst of invisible infrared light. When fired accurately the electric eye in the target detects the light and flips the target indicating a "hit". Investigation of the Infrared Target Pistol was discontinued early largely because the accuracy of the target pistol proved to be highly questionable. First, the target seemed to indicate "hits" when subjects aimed above the bull's eye rather than directly at it. Second, subjects' scores appeared very unstable. Scores for individual subjects ranged from very low (one or two hits out of 10) to high (eight or nine hits out of 10). Such erratic scores were also found for one investigator who has qualified as an expert marksman

with a .45 in the military service. Finally, while the manufacturers of the pistol stated that it had a range of 60 feet the target could not detect the light at 45 feet. The distance for military pistol qualifications is 50 feet.

MULTI-SENSORY COORDINATOR SYSTEM

The Multi-Sensory Coordinator System is a translucent screen to which various paper patterns are attached and back-lighted. Patterns include approximately quarter-inch wide straight-line and curved-line paths, as well as mazes, to be traced by the subject using a sensor pen. Errors are automatically recorded and completion time is recorded with a stopwatch.

Investigation of this test was discontinued early for several reasons. Though the paper patterns were designed to last through 20 trials, some of them became scratched after fewer than 10 trials. This caused light to show through the pattern and false errors to be recorded. Further, if the pen was not held almost exactly perpendicular to the pattern it picked up overhead lights and recorded false errors. Finally, this test appeared to be redundant with other paper and pencil tests.

PSYCHOMOTER PERFORMANCE EVALUATION BATTERY

In seaching for a computerized keyboard test of dexterity/tactility, the Psychomotor Performance Evaluation Battery (PPEB) was reviewed for possible use in the CD treatment drug testing battery. Due to the lack of proper equipment, only three of the seven PPEB tests (Forced Choice Reaction Time, Stroop-Color Test, and Multiple Task Performance Battery) were reviewed. The PPEB is run on an Apple II microcomputer which scores each test automatically.

Forced Choice Reaction Time. This test presents a row of four squares on a monitor. Above the squares are corresponding Roman numerals ranging from I to IV. When one of these squares is randomly illuminated, the subject's task is to push the response button corresponding to the illuminated square. A new trial appears immediately after each response, so the faster the subject's response time, the more trials will appear during the two-minute program. The test is computer-scored by the number of presentations, correct responses, errors, and average reaction time. A mental arithmetic test is usually given with this test but was not used for this study.

The techniques subjects used in this task varied a great deal. Some used four fingers and others only one or two. Though this test could be standardized, the measure would include cognitive aspects in addition to dexterity skills.

Stroop Color Test. On this test a series of four color words appear in color on the screen: red, green, yellow and blue. However, no color name appears in its own color (e.g. the word "blue" might appear in red). Each color word is numbered from I to IV. Before each series appears on the screen, the subject is given an instruction in the form of one of two cues: either WORD followed by a color, or COLOR followed by a designated color (e.g. WORD-RED or COLOR-BLUE). The subject's task is to press the numbered button corresponding to the correct cue. That is, if the cue instructs him to identify WORD-RED, he would press the number which designates that word

regardless of the color in which it appears. If his cue says COLOR-BLUE, he presses the number corresponding to whichever word appears in blue, regardless of what it says. The task runs for two minutes. The rate of presentation is controlled by subjects' reaction times. The faster they react, the more presentations they will receive. The computer scores number of presentations, correct responses, errors, and average reaction time. The Sternberg Memory Task is usually given with the Stroop Test but was not used for this study.

The Stroop Test is a choice reaction time test. The subjects must mentally choose a response before pushing the corresponding button. Hence, two separate reaction times (mental processing and wrist/finger speed) are recorded. Because mental processing is a large component of the test, the test would not provide an accurate measure of dexterity.

Multiple Task Performance Battery (MTPB). The MTPB consists of five tasks: arithmetic operations, target identification, probability monitoring, warning light monitoring, and blinking light monitoring. The program is written so that the latter three tests are run together and the arithmetic and target identification can be added separately or together. Because the probability, warning light and blinking light monitoring tasks seemed to provide more accurate measures of reaction times, only these three tests were studied. The arithmetic and target identification tasks appear to be measures of memory and concentration rather than dexterity.

In the probability monitoring task four sets of vertical lines are displayed on the monitor. Each set has a dot located under the display which moves in a specific pattern. The four sets of lights move in the same pattern but independently of one another. The subject's task is to monitor the four sets for pattern breaks and press the corresponding button for the set which has changed. If the subject fails to respond in two minutes, the lights resume their normal pattern.

In the warning light monitoring task, a rectangle formed by two squares is presented on the screen. In the normal state, a "G" is displayed in the top box. The subject's task is to press a button when the "G" disappears from the top box and an "R" is displayed in the bottom box. If subjects fail to respond in five seconds, the warning light returns to normal.

In the blinking light monitoring task, a rectangle like the one described above is displayed. A smaller illuminated square alternates between the upper and lower squares. Subjects monitor the blinking squares and press a button when the illuminated square stops alternating and simply blinks in one square. If subjects fail to respond in 30 seconds, the light returns to normal.

For each of the three tests, the number of correct responses, missed presentations, false alarms, performance and reaction times are recorded by the computer. The length of time the MTPB will run is programmable. For this study it was set at three minutes. The number of presentations for each task within the three minutes ranged from zero to six with the warning light having the most presentations and probability monitoring the fewest.

Though reaction time is a component of this test, the test appears to be more basically a measure of workload. For this reason, the MTPB was discontinued from battery consideration.

APPENDIX B

TEST ADMINISTRATION PROCEDURES

This packet includes descriptions of each test, numbered as they are on the data sheet (see Figure B-1), the test instructions as they are given to subjects, scoring procedures, and administration procedures.

I CONSENT FORM - Prior to testing, subjects read and sign both sides of the consent form and the experimenter signs it as a witness. Subjects are asked if they have any questions.

II DATA SHEETS - Entered on the top part of each data sheet is demographic information, such as the subject's name, age, and handedness, as well as dates of testing and an assigned subject number. Subjects are assigned numbers (1 to 60 for males, and 61 to 120 for females) and entered into a log. The order in which the tests are to be given is randomly assigned and filled out in advance on the data sheets. Subjects complete 13 tests the first session and 13 the second session. Each session is two and a half to three hours long. Under no circumstances does a subject complete both sessions in one day.

A. X=prior exp. - This column indicates whether a subject has performed this exact test (not a similar one) before. These data may be used in the future to study learning curves.

B. Test No. - Attached to each piece of test equipment is a number corresponding to the number on the data sheet attached to it. This is designed to assist experimenters in locating equipment.

C. Practice Trials - Under each test title is a series of 3 to 12 lines for practice scores. The number of practice trials required for each test was determined after extensive pilot testing to determine where scores plateaued. Following the specified number of practices, the subject performs a final time for data analysis. Subjects are told when they are performing the "real" test because they tend to try their best for the one that counts, even if they are bored. They are also encouraged to rest before the last trial so that they can perform at their best. All subjects perform the same number of practice trials for a given test and are encouraged to use the practice trials to explore different techniques to find the best ones for them. The experimenter does the disassembly tasks when they are required so that subjects may rest their hands. Subjects are watched especially closely the first few trials to ensure that they follow directions.

D. Comments - This section of the data sheet includes any pertinent information regarding the subject's performance, the test equipment, and observations made by the subject or the experimenter.

DEXTERITY BATTERY

NAME_____ HANDEDNESS: R L A

SUBJECT NO._____ AGE_____

SEX: M F DATE PART I_____

PART II_____

TEST/PRACTICE TRIALS

X=prior exp.	Test Order	Test No.		Scores
_____	3	1.	Manipulative Aptitude Test, Rods & Caps, 2 min.	
			_____ _____ _____ _____ _____	1._____
_____	13	2.	Manipulative Aptitude Test, Washers & Nuts, Dominant, 30 sec.	
			_____ _____ _____ _____ _____	2._____
_____	23	3.	Manipulative Aptitude Test, Washers & Nuts, Both, 30 sec.	
			_____ _____ _____ _____ _____	3._____
_____	19	4.	Tapping Test, Apple IIE	
			_____ _____ _____	4._____
_____	18	5.	Purdue Pegboard, Assembly, 1 min.	
			_____ _____ _____ _____ _____ _____ _____	5._____
_____	15	6.	Purdue Pegboard, Pins, Dominant, 30 sec.	
			_____ _____ _____ _____ _____	6._____
_____	1	7.	Purdue Pegboard, Pins, Both, 30 sec.	
			_____ _____ _____ _____ _____	7._____
_____	5	8.	Reaction Time, Apple IIE	
			_____ _____ _____ RT _____ _____ _____ FS _____ _____ _____ ER	8._____RT _____FS _____ER
_____	21	9.	Pennsylvania Bi-Manual Worksample, 2 min.	
			_____ _____ _____ _____ _____ _____	9._____
_____	4	10.	Crawford Small Parts Dexterity, Screws, 2 min. 30 sec.	
			_____ _____ _____ _____ _____	10._____
_____	6	11.	Crawford Small Parts Dexterity, Pins & Collars, 2 min. 30 sec.	
			_____ _____ _____ _____ _____	11._____
_____	7	12.	O'Connor Finger Dexterity, 3 min.	
			_____ _____ _____ _____ _____	12._____
_____	17	13.	Minnesota Rate of Manipulation	
			_____ _____ _____ _____ _____	13._____

Figure B-1. The data sheet.

X=prior exp.	Test Order	Test No.		Scores
_____	24	14. Two-Arm Coordination Test	_____ _____ _____ _____ _____ _____ ET _____ _____ _____ _____ _____ _____ CT _____ _____ _____ _____ _____ _____ ET _____ _____ _____ _____ _____ _____ CT	14. _____ ER _____ CT
_____	14	15. Grooved Pegboard, 30 sec.	_____ _____ _____ _____ _____	15. _____
_____	25	16. Mirror Trace Test	_____ _____ _____ _____ _____ _____ ER _____ _____ _____ _____ _____ _____ CT _____ _____ _____ _____ _____ _____ ER _____ _____ _____ _____ _____ _____ CT	16. _____ ER _____ CT
_____	16	17. Photoelectric Rotary Pursuit, Square, 10 laps	_____ _____ _____ _____ _____ off _____ _____ _____ _____ _____ on	17. _____ off _____ on
_____	20	18. Photoelectric Rotary Pursuit, Circle, 10 laps	_____ _____ _____ _____ _____ off _____ _____ _____ _____ _____ on	18. _____ off _____ on
_____	8	19. Groove Steadiness	_____ _____ _____ ET _____ _____ _____ CT	19. _____ ET _____ CT
_____	26	20. Tracing, 30 sec.	_____ _____ _____ _____	20. _____
_____	10	21. Pursuit Aiming II, 60 sec.	_____ _____ _____ _____	21. _____
_____	22	22. Medium Tapping, 30 sec.	_____ _____ _____ _____	22. _____
_____	9	23. Aiming Test, 30 sec.	_____ _____ _____ _____	23. _____
_____	12	24. Steadiness Test, 30 sec.	_____ _____ _____ _____	24. _____
_____	2	25. Numeric Keypad, Apple IIE	_____ _____ _____ _____ ER _____ _____ _____ _____ CT	25. _____ ER _____ CT
_____	11	26. Nine-Hole Steadiness	_____ _____ lg ET _____ _____ sm ET	26. _____ lg ET _____ sm ET

COMMENTS _____

_____

_____

_____

_____

Figure B-1. (continued)

III LOG - In addition to recording subjects' names, numbers and testing dates, the experimenter keeps a log of observations and comments made during testing.

IV TESTING PROCEDURES -

A. Subject Position - With the exception of the Minnesota Rate of Manipulation, the Two Arm Coordination Test and the Rotary Pursuit, all of the tests are performed while sitting.

B. Dropping Parts - Most of these tests have many extra parts, and subjects are instructed to ignore dropped parts and retrieve new ones from the wells. The one exception is the Minnesota test, a brief test which subjects usually don't mind starting over.

C. Equipment Position - Each test is placed in the same position for all subjects. That is, if its instruction says "well at top", subjects may not angle the board. They may, however, adjust equipment distance from edge of table to allow for longer or shorter arms.

D. Dominant Hand Tests - For tests which are one-handed, the other hand may be used to steady equipment or hold paper in position. If a subject is ambidextrous, he or she may use whichever hand is preferred.

E. Descriptions - Experimenters demonstrate the use of each test while giving instructions and answering any questions. Subjects are given five minutes between each test and are frequently asked if they would like a break. Some of these tests use the same equipment as others (for example, tests #1, #2 and #3 use the same board) and, in these cases, general instructions for positioning the equipment precede instructions for the individual tests.

TESTS

#1,#2,#3 The Manipulative Aptitude Test is positioned so wells are near table's edge and the T-Bar is at the top. The long edge of the board should be parallel with the edge of the table.

#1 MAT Rods and Caps

To Subjects - This test measures how quickly you can screw in a rod, and screw a cap on top. Use your dominant hand and pick up one rod at a time, screw it into a hole then screw a cap on top. Start in the top corner opposite your dominant hand, and work across the rows. You will have five practice trials and will be scored by the total number of pieces placed in two minutes. Starting position is with a rod in hand and hand resting on the table.

To Experimenter - Make sure during practice trials that the caps are screwed on and not just sitting on top of the rod, and that subjects perform all rows in the same direction.

#2 MAT Washers and Nuts, dominant

To Subjects - This test measures how quickly you can place pieces on a T-Bar. Beginning with a washer, you use your dominant hand to place a washer (sliding it to the end) and then a nut on to the end of the T-Bar closest to your dominant hand. Continue alternating pieces for 30 seconds. You will be given five practice trials and your score will be the total number of pieces placed. Beginning position is with a washer in hand and hand on the table.

To Experimenter - Make sure each piece is pushed to the middle before subject picks up another.

#3 MAT Washers and Nuts, both hands

To Subjects - This test measures how quickly you can place washers and nuts on a T-Bar using both hands. You begin with a washer in each hand, place them on the T-Bar at the same time, slide to the middle, then pick up nuts and do the same. Continue alternating between washers and nuts for 30 seconds. You will be given five practice trials and your score will be the total number of pieces placed. Beginning position is with a washer in each hand, and hands resting on the table.

To Experimenter - Make sure each piece is pushed to the middle before subject picks up another. Hands must work is unison, i.e. doing the same thing at the same time.

#4 Tapping Test, Apple IIE

To Subjects - This test is performed on a computer and measures how many times you can tap your finger in a 10 second period. You rest your hand on the table and may tap any key on the numeric key pad. The 0 key is closest to the edge but select the key you are most comfortable with. You will use the index finger of your dominant hand. Begin tapping when the computer instructs. You will be given three practice trials.

#5,#6,#7 Purdue Pegboard (PP) - This is a long white board with two columns of holes and four wells at the top. The bottom edge of the board should be parallel with the edge of the table.

#5 PP Assembly

To Subjects - This test measures how quickly you can assemble four pieces using both hands in an alternating fashion. You begin by inserting a rod with your right hand, placing a washer over it with your left, putting on collar with your right and another washer with your left. Your left works with washers and your right alternates between rods and collars. As one hand is placing a piece, the other hand is picking up the next piece. In other words, at least one hand is always in motion. Your score is the number of pieces placed (i.e. each completed assembly = 4) in one minute. You will be given seven practice trials. Starting position is with a pin in your right hand and both hands on the table.

To Experimenter - Some subjects have difficulty mastering the rhythm. If they appear to have problems after the first one or two trials, offer suggestions and redemonstrate.

#6 PP Pins, dominant

To Subjects - This test measures how quickly you can insert pegs in a hole picking them up one at a time. Using your dominant hand, place a pin in the top hole and work down, using the column closest to your dominant hand. You will be given five practice trials and your score will be the total number of pins placed in 30 seconds. Starting position is with a pin in your dominant hand, and hand resting on the table.

To Experimenter - Have subjects go back to the well for each pin. They are not to pick up pins which may be rolling down the board.

#7 PP Pins, Both hands

To Subjects - This test measures how quickly you can insert pairs of pins using both hands in a uniform fashion. Each hand picks up one pin at a time from the well closest to that hand, and places it in the closest column, starting at the top and working down. You will be given five practice trials and your score is the number of pairs placed in 30 seconds. Starting position is with a pin in each hand and hands on the table.

To Experimenter - Make sure subjects' hands move in matching fashion. They are to go to wells for each pin and not pick up pins rolling down.

#8 Reaction Time, Apple IIE

To Subjects - This test measures how quickly you can respond by tapping the #5 key after seeing a visual stimulus (a question mark). The time interval between each stimulus presentation ranges from 1/2 to 5 seconds. There are 10 stimuli in each trial and you will be allowed three practice trials. You will use the index finger of your dominant hand and may rest your hand on the table. You may leave your finger above the key but not in contact with it. You will be scored by the average reaction time of the 10 presentations, the number of false starts (key is struck before stimulus is presented) and number of errors (wrong key is hit).

To Experimenter - Most subjects' average reaction times are .5 or less. If score appears excessively large, it may be due to a computer error and the subject should repeat the test.

#9 Pennsylvania Bi-Manual Worksample - Place board so bolts are near the dominant hand.

To Subjects - This test measures how quickly you can assemble nuts and bolts. You pick up a bolt with the dominant hand and a nut with the other. Turn the pieces until they just catch and place the assembly, bolt side down, in the top corner opposite your dominant hand. While your nondominant hand places the assembly in the hole, your dominant hand reaches for another bolt. Work across the rows. If you drop a bolt in a hole, skip that hole and I will remove it later. You will be given six practice trials and your score will be the number of assemblies completed in two minutes. Starting position is with a piece in each hand and hands resting on the table.

To Experimenter - One turn is sufficient to engage the pieces. Watch subjects for screwing pieces together more than necessary.

#10,#11 Crawford Small Parts Dexterity Test - Arrange board so wells are at the top with bottom edge parallel to table edge. The metal plate should be positioned so that the larger holes for screws are below the well for screws.

#10 Screws

To Subjects - This two-handed test measures how quickly you can turn screws through a plate using a screwdriver. Use your dominant hand to catch the screw in the hole (turn screw no more than needed to just catch it) and then use the screwdriver (using both hands) to turn the screw through the plate. You will hear the screw hit the plate and feel it "give" when it goes through. You may place your fingers over the point at which the screwdriver and screwhead meet if you have problems with the screwdriver slipping off. Begin in the top corner opposite your dominant hand and work across. You

will be given five practice sessions and will be scored by the number of screws completed in two minutes and 30 seconds. Starting position is with the screw in your dominant hand and the screwdriver in your other, with both hands on the table.

To Experimenter - Subjects may use their nondominant hand to start screws if they prefer. Screws are easily removed by sliding the plate to the side. Watch for the plate sliding out of position during testing or subjects will hit wood below. If you find that screws are not completely turned through, point it out to subject. Any screws which are incomplete when the allotted time is up are not counted.

#11 Crawford Pins and Collars

To Subjects - This test measures how quickly you can insert a pin in a hole and a collar on top using tweezers. Using your dominant hand, pick up a pin and insert it in a hole starting at the top corner opposite your dominant hand. You then pick up a collar and place it over the pin, wide side down. Work across the rows. You will be given five practice trials and will be scored by the number of pieces in position in two minutes and 30 seconds. Starting position is with tweezers in hand and hand on table.

To Experimenter - Subjects are to return to wells for pieces and are to use their dominant hand only.

#12 O'Connor Finger Dexterity Test - Position board with pins at top.

To Subjects - This test measures how quickly you can insert three pins at a time in one hole using your dominant hand. Pick up three pins at once and place in a hole, starting at the top corner opposite your dominant hand, and work across. If a pin falls out after it was placed in a hole, it does not have to be replaced. You will be given five practice sessions and will be scored by number of holes filled in three minutes. Starting position is with three pins in hand and hand on table.

To Experimenter - All pins are to come from the well. Holes with four pins can be counted but subjects should be reminded to pick up only three if this occurs frequently.

#13 Minnesota Rate of Manipulation - This test is done standing. Position board so that long edge is parallel with the table edge. All pegs should be turned to the same color.

To Subjects - This test measures how quickly you can turn pegs over using both hands. Starting in the top right corner, pick up a peg with your left hand, and return it to the same hole with your right hand, bottom side up. Work to your left on the top row, then drop down one row and work to your right, picking up the peg with your right hand, and returning it to the hole with your left. In other words, pick up with the lead hand and replace with the following hand, working in an "S" pattern. Because there is only one peg for each hole, you will have to start over if you drop one. All pegs must be lying flat at the end. You will be given five practice trials and will be scored by completion time. Starting position is with your left hand resting on the top right peg.

To Experimenter - Subjects often like this test. Left and right handed subjects do this the same way. Make sure subjects pick the pegs up out of the hole, rather than rolling them over.

#14 Two Arm Coordination Test - Position the board so that the short end is parallel with the table edge and handles are toward subject. Press the board down to stabilize suction cups on bottoms. This test is done standing.

To Subject - This test measures how quickly you can move a stylus around a star pattern using both hands. Begin with the stylus in the bottom middle of the pattern and move the stylus clockwise, staying on the pattern, until you return to the starting position. You will be given 12 practice trials and will be scored by completion and error time. The emphasis is on accuracy. Starting position is with both hands on the handles, and with the stylus at the bottom center point on the star.

To Experimenter - Subjects tend to be slow at first but improve quickly. Make sure the stylus is not lifted off the board. If subjects have excessive error time and are racing around the board, remind them that the emphasis is on accuracy.

#15 Grooved Pegboard - Position the board with pegs at the top and the short edge parallel with the table.

To Subjects - This test measures how quickly you can insert a peg in a hole using your dominant hand. Beginning with the top corner opposite your dominant hand and working across, pick up one peg at a time, turn it to fit the hole and insert. You will be given five practice trials and will be scored by number of pegs placed in 30 seconds. Starting position is with a peg in your dominant hand, and hand on the table.

#16 Mirror Tracer - Position the mirror so the subject gets the best view of the pattern, and adjusts the screen so the hand cannot be seen but there is enough room for the pen (allow subjects to adjust). Use bolts to tighten. Place the double star pattern under the clips so the pattern is not obscured. Use fine-point red pen.

To Subjects - This test measures how quickly you can draw a line through a pattern while looking at an inverted, reversed picture. After you place your pen in the bottom middle of the pattern you are to look in the mirror only, and draw a continuous line. Move in a clockwise direction until you return to the starting position. The object is to stay between the lines but to move as quickly as possible. You will be given 12 practices and will be scored by completion time and number of errors. Starting position is with the pen touching the bottom middle of pattern.

To Experimenter - A few subjects may have problems learning this test. If someone appears to have problems, stop and coach the subject. It is often helpful to advise subjects to ignore what they see and rely more on their sense of direction with their hand. Example: "By looking at the pattern you see you now have to go up and right. Close your eyes and move your hand upward, and to the right." Over five errors (when red is seen outside the outer black line) are too many. Reemphasize accuracy.

#17,#18 Photoelectric Rotary Pursuit - This test is done with subjects standing to the side and the experimenter seated in front of the equipment. The patterns are changed by loosening screws in back and sliding the plate out. The instructions for both patterns (square and circle) are identical.

To Subjects - This test measures how quickly you can follow a moving light with a stylus. The light begins at the top of the pattern and moves in a clockwise direction at a speed of 20 rpm. The stylus should be held directly over the light but does not need to be in contact with the glass. You will be given five practice trials of 10 laps each and will be scored by time on and time off target. Starting position is with stylus in hand and the point over the light. I will count to three before beginning, and will tell you when the last lap begins.

To Experimenter - Use the internal/external switch to start pattern. This keeps light on but stops motion. Make sure clocks and lap counter (impulse counter) are reset each time.

#19 Groove Steadiness - Position the board so the groove is parallel with the table edge.

To Subjects - This test measures how accurately and quickly you can move a stylus down a narrow groove. Holding the stylus with

your dominant hand by the red plastic part (holding it by the metal tip may result in static electrical shocks), place the stylus tip at the beginning of the groove opposite your dominant hand. Keeping it in contact with the plate below, and without resting your hand, move the stylus, as quickly as possible, in between the plates without touching the sides. You will be given three practice trials and will be scored by completion and error time. Starting position is with the stylus tip in contact with the plate at the end of the groove.

#20 - #24. Paper and Pencil Tests - some of these tests use the fine-point red pens (#20, #22, and #24), while others use the thicker felt tips (#21 and #23). A good rule of thumb is: if it requires one dot, use the softer point. All of these tests are positioned so that the shorter end of the paper is parallel with the table edge. In all of these tests, a time limit is given and subjects are scored by number completed minus errors. The emphasis is on accuracy. If subjects have over five errors, reemphasize this.

#20 Tracing - Fine-point pen

To Subjects - This test measures how quickly and accurately you can draw a continuous line through a maze without touching the sides. An error is counted whenever the pen mark comes in contact with the pattern line. You will be given four practice trials and will be scored by number of gates successfully negotiated in 30 seconds. The emphasis is on accuracy more than speed. Starting position is with the pen tip touching the arrow at the left corner of the maze.

To Experimenter - If you can't see the white of the paper between pen line and test lines, it is an error. Circle the errors as you see them to make scoring easier. The score is the number of errors subtracted from the number of the last completed gate.

#21 Pursuit Aiming II - Soft-point pen (see above under Paper and Pencil)

To Subjects - This test measures how quickly and accurately you can place dots inside small circles following an erratic pattern. An error is counted whenever a pen mark is clearly outside the circle; a pen mark on the border is not an error. You will be given four practice trials and will be scored by number of dots placed inside circles in 60 seconds. The emphasis is more on accuracy than speed. Starting position is with pen in hand and hand resting on table.

To Experimenter - Circle errors and score by subtracting the number of errors from the number of the last circle completed.

#22 Medium Tapping - Fine-point pen

To Subjects - This test measures how quickly and accurately you can place three distinct dots in a small circle. If the three dots are not distinct, it is counted as an error. Beginning in the top corner opposite your dominant hand, place three dots in the circle and then work across the row going in the same direction for all rows. You will be given four practice trials and will be scored by the number of circles completed in 30 seconds. The emphasis is more on accuracy than speed. Starting position is with pen in hand and hand on table.

To Experimenter - The dots must be distinct or they do not count. Circle errors and subtract the number of errors from the number of the last completed circle (there are 10 circles in each row).

#23 Aiming Test - Soft-point pen

To Subjects - This test measures how quickly and accurately you can place a single dot inside a small circle. The dot must clearly be inside. Beginning in the top corner opposite your dominant hand, place a dot inside and work across the row going in the same direction for each row. You will be given four practice trials and will be scored by the number of circles completed in 30 seconds. The emphasis is more on accuracy than speed. Starting position is with pen in hand and hand on table.

To Experimenter - There are 10 circles in each row. Circle errors then subtract the number of errors from the number of the last completed circle.

#24 Steadiness Test - Fine-point pen

To Subject - This test measures how quickly and accurately you can draw a continuous line through a pattern without crossing the lines. Starting at the arrow in the top left corner, draw a line without crossing the sides. Use your dominant hand and do not lift the pen after you have started. An error is counted whenever a red pen mark can be seen outside the lines. You will be given four practice sessions and will be scored by the number of completed segments that have no errors in 30 seconds. The emphasis is on accuracy more than speed. Starting position is with the tip of the pen placed on the dot in top the left corner.

To Experimenter - Circle segments with errors and subtract the number of errors from the number of the last completed segment. If the subject goes outside the line on one segment, and back on the next segment, this constitutes two errors.

#25 Numeric Key Pad, Apple IIE

To Subjects - This test measures how quickly and accurately you can duplicate the 15 numbers ranging in length from 3 to 10 digits. As the numbers appear on the screen, duplicate them using the index finger of your dominant hand on the numeric key pad. The return button must be pressed before the next number will appear. If you make a mistake, you can use the arrows to return to the wrong digit but once the return button is pressed, the error is recorded. An extra number will cause all numbers to the right to be seen as errors. For example, if the number is 45672 and you enter 455672, three errors will be recorded because the 6, 7, and 2 are all out of position. You will be allowed four practice trials and will be scored by completion time and number of errors. Accuracy is emphasized more than speed. Starting position is with your hand on the table and the index finger over but not touching the keys.

To Experimenter - Errors and completion time are recorded by the computer. Round off completion time to the nearest hundredth.

#26 Hole Steadiness - The largest and the smallest of the holes will not be used. Position the metal frame so that the long edge is parallel with the table's edge and the holes are facing the subject.

To Subjects - This test measures how steadily you can hold a stylus in holes of gradually smaller sizes without touching the sides. Holding the stylus by the red plastic part (holding the metal tip may result in static electrical shocks) in the dominant hand, insert the tip half-way through the hole. When you are ready, a 10-second interval will be started, after which you can pull it out. Your scores will be the total error time for two sets of four holes--four large and four small. Holding your breath during the 10-second interval may help to steady your hand. You will do the first four holes (the larger ones) with your hand unrested, and the last four (repeating the bottom left hole) resting your hand in any manner. Though the timer indicates when 10 seconds is up, do not pull the stylus out until I say to, because errors will continue to be recorded for a few seconds after the timer stops. You will be given two practice trials for each set.

To Experimenter - Allow subjects to rest their hands in between holes, especially before the final trial. Turn the electric panel switch off as soon as 10 seconds are up. Listen for the hum of the clock to stop before telling subjects to pull out. If an error is recorded on pull-out, subtract this time from their score. Subjects are to alternate between the large and small holes.

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